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A further evaluation and extension of criteria of physical-plant utilization.

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A FURTHER EVALUATION AND EXTENSION OF CRITERIA
OF
PHYSICAL-PLANT UTILIZATION

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ABSTRACT

Ten indices have previously been proposed as measurements for the evaluation of physical-plant utilization. This paper is a further extension and validation of these proposals. Plant layouts vary according to the specific items manufactured, processes required, and many other factors. In attempting to validate these indices it was necessary to find some criterion of improved plant layout. This validation was accomplished by evaluating only plants manufacturing the same item under two conditions of plant layout, initial and revised. The criterion of improvement was established either quantitatively, such as increased production or savings; or qualitatively, such as increased safety or improved inspection. Three methods were considered in performing this evaluation; first, a survey was made of "before and after" literature, written for technical journals, which described new and improved plant layouts. Second, a questionnaire-type list was proposed to be distributed to the Production Engineering Departments of factories having records of revised layouts. And third, actual plant visits for the purpose of making the necessary physical measurements of existing or proposed layouts, as well as making detailed studies of available files, records, blueprints or template layouts. The last method was decided upon. Five factories in the Central Indiana area were chosen for study. A fairly heterogeneous selection of manufactured

items were analyzed from the plant layout viewpoint. The evaluation also included departmental and divisional layout analysis in order to provide a more comprehensive appraisal of the indices. Constant effort was exerted to evaluate the improved criteria factors, such as increased production, only in the light of changed layouts. Many cases exist where the same criteria are a result of better methods or processes, and these cases were carefully eliminated.

Conclusions and Recommendations

In the validation of the criteria certain changes were made, such as clarifying, generalizing and re-defining, in order to make the terms more universal in application. Two of the original indices were set aside and two additional indices were proposed and partially validated. In evaluation, the indices were found to be more easily applied if arranged in the following groups:

Flow of the Manufactured Part

1. Index of Indirect Materials Handling
2. Index of Total Materials Handling
3. Index of Gravity Utilization

6(a). Index of Production Line Flexibility

Utilization of Men and Machinery

4. Prime Index of Automatic Machinery Loading
5. Secondary Index of Automatic Machinery Loading

6(b). Index of Work Station Flexibility

7. Index of Floor Area Loading Density

8. Index of Aisle Space

9. Index of Storage Space

10. Index of Storage Volume Utilization

The above indices may be used separately or in combinations, depending on the particular situation encountered. There is an advantage noted in analyzing the numerical values of certain indices with respect to one another.

The indices evaluated and retained in this paper are now considered to be valid criteria of physical-plant utilization. Further research not far afield might include the development of general standards of index values within industries, the correlation of index values with common industrial criteria, and the development of a similar set of indices for other Industrial Engineering techniques.

A FURTHER EVALUATION AND EXTENSION OF CRITERIA OF PHYSICAL-PLANT UTILIZATION

THE PROBLEM

Two problems present themselves for solution in this paper. The first problem is to prove that the indices previously proposed are or are not criteria of physical-plant utilization. The second problem is to develop, analyze and evaluate further indices of physical-plant utilization.

In solving the first problem it will be necessary to bridge the gap between theory and practice - that is, to properly evaluate the proposed criteria it will be necessary to apply these criteria to actual, practical situations. In doing this, close attention will necessarily be paid to terms, definitions, and their related meanings, to insure that such are general enough to be applicable to all conceivable situations. Further, the proposed indices must not only be evaluated from the standpoint of the immediate results to be obtained therefrom but they should be also viewed in the broad sense of applicability, such as which indices should be usod and how, where, and when they should be used.

The solution of the second problem should evolve from an analysis of the material, methods, procedures and experience used in obtaining a solution to the first problem. Throughout this paper, constant endeavor shall be maintained to develop and appraise all indices from the point of view of pure physical-plant utilization.

GENERAL PROCEDURE

This paper will be developed and organized as follows:

First, a review of the previously proposed criteria of physical-plant utilization will be undertaken. This will include definitions of terms used, meanings of each symbol or letter, and the intended use for each criterion.

Second, a detailed analysis of the proposed criteria will be presented. This analysis will attempt to show the conditions required for applications of the criterion with optimum results. Certain terms will be re-defined or generalized in the light of the experience gained by application of these criteria to different practical situations. Likewise, the meanings of certain symbols will be modified to permit their wider use in more diversified industrial situations. Proposed criteria which do not fulfill the requirements of proper evaluation in terms of physical-plant utilization only, will be eliminated.

Third, further criteria for the evaluation of physical-plant utilization will be developed. These criteria will be designed to alleviate certain voids created in the evaluation of plant layouts with the indices previously proposed. These criteria will be structured and defined so as to be applicable under the same conditions of usage as were the previous criteria.

Fourth, a procedure for the evaluation of physical-plant utilization will be outlined. The methods proposed for performing this evaluation will be examined. The final selection of one of the proposed methods, as well as the reasons

for that selection, will be set forth in detail. The benefits and experience gained from this particular chosen method of evaluation, as well as the limitations and difficulties encountered, will be discussed.

Fifth, the criteria of physical-plant utilization will be evaluated by actual application to existing plants. This application will be confined only to those plants having manufactured the same product under two conditions of layout - original and improved. A brief summary of the plant operations, products and background will be presented. The criterion of betterment of the improved layout will be indicated. Each index will be evaluated under both conditions of layout and will be enumerated with such pertinent remarks as may apply.

Sixth, a critique will be presented. This will be a critical estimate of each of the indices previously evaluated. In this presentation each index will be discussed as to its applicability, function and significance.

Lastly, general conclusions and recommendations will be deduced from the development and application of these indices to practical situations. These remarks will pertain to the capabilities and limitations of each of the indices, as well as their recommended use, either in combination or individually, for optimum utility. Recommendations will be made for further areas of research which would enhance the value of the present work in the field of evaluation of physical-plant utilization.

REVIEW OF PREVIOUSLY PROPOSED CRITERIA

A review of previously proposed criteria of physical-plant utilization is in order at this point.[1] These criteria, or indices, are as follows:

1. Index of Indirect Materials Handling = $\frac{a}{b}$

   where a = the sum of the distances a part moves automatically by conveyor and from machine to machine arranged in operation sequence without external materials handling.

   and b = the total actual distance a part moves via the production route from raw stores to finished stores.

This index shows the efficiency of the production route through use of mechanized handling of materials. Here, "external materials handling" means movement of production materials from one location to another, in boxes, tote pans, etc., by _any_ person.

2. Index of Direct Materials Handling = $\frac{c}{b}$

   where c = the direct line distance via the plant floor from raw stores to finished stores.

This index depicts the manner in which the manufacturing route is laid out.

3. Index of Gravity Utilization = $\frac{d}{e}$

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1 Gantz, S.P., "A Proposal of Criteria for the Evaluation of Industrial Physical-Plant Utilization", M.S. Thesis, Purdue University, June 1950.

where d = the sum of the vertical distance gravity feed used.

and e = the total vertical distance up a part moves from raw stores to finished parts.

This index shows the extent of utilization of gravity in returning to the main floor parts lifted therefrom.

4. Prime Index of Automatic Machinery Loading = $\frac{f}{100g}$

where f = the sum of the percentages of machine down time from all cases where the individual percentages of down time are equal to or less than 50% of the individual work cycles.

and g = the total number of operators on those machines.

This index points out the efficiency in grouping machines for multi-machine operation. In this index "down time" means that portion of the work cycle in which the machine is loaded and unloaded. It is to be noted that this index is used only for machinery for which the machine time portion of the overall work cycle is automatic and machines may be left unattended while operating.

5. Secondary Index of Automatic Machinery Loading = $\frac{h}{100g}$

where h = the sum of the percentages of machine down time from all cases where the individual percentages of down time are greater than 50% of individual work cycles.

The same remarks apply as in Index #4, except that this index is used only for odd groupings of machines which might not

conceivably be adapted to that index.

6. **Index of Flexibility** $= \frac{j}{k}$

where j = the number of machines capable of being moved to a new location in the production line in one working shift.

and k = the total number of machines in the production line.

This index shows the ability to change a machinery layout rapidly.

7. Index of Floor Area Loading Density $= \frac{\sum[(m+2)(n+2)+p]}{q-r}$

where m = extreme machine length in feet

n = extreme machine width in feet

p = operator work area in square feet

q = total plant floor area in square feet

and r = total aisle area in square feet

This index shows the manner in which plant floor area is utilized. Here, "machine" means all production machinery including conveyors resting on or near the floor, but excludes overhead conveyors which pass over and clear of other machinery.

8. Index of Aisle Wastage $= \frac{q-r}{q}$

where q = total plant floor area

and r = total aisle area

This index shows how much floor area is consumed by aisles.

9. Index of Time $= \frac{s}{t}$

where s = the sum of the standard times for all operations on a part..

and t = the total standard times for the part, raw stores to finished stores including handling time and time in banks.

This index measures the time efficiency with which a part traverses the production process. In this index, "operations" means the active work on the part in production, i.e., modification of a part in one location.

10. Index of Inventory = $\frac{x}{y}$

where x = rate of production

y = index of time

This index shows the number of production units planned for the production line at any one time.

ANALYSIS OF PREVIOUSLY PROPOSED CRITERIA

In applying the proposed criteria of physical-plant utilization to different practical situations, several modifications and alterations to these indices seemed pertinent. Although a fairly wide selection of plant layouts was used, and the experience gained therefrom has been of great value in making these indices more universal in application, it is appreciated that such definitions, terms and meanings, as herein employed, will be under constant revision. This revision and upgrading should be inherent in all phases of modern industrial techniques.

In the original proposal of these criteria it was theorized that certain ones should be applied to those plants engaged in continuous production, whereas certain others should be applied to those plants engaged in intermittent production. However, in actually using these indices, in measuring the layout, it was noticed that they logically fell into two readily classifiable groups, as follows:

(1) Those indices which best describe the proper layout with respect to the <u>flow of the part</u>.

(2) Those indices which best describe the proper layout with respect to the <u>utilization of men and machinery.</u>

Each index, in all cases of application, fell naturally into one of these groups. It is this classification that determined the method of orienting the data involved, when actually applying these criteria to existing plants.

One more assumption should be presented before continu-

ing with the step-by-step analysis of each index. Layout and re-layout are not necessarily concerned with the entire plant nor do they necessarily affect all parts of a given product. In the majority of instances, the layout or re-layout is concerned with the rearrangement of the departmental, sectional, or even smaller organizational unit.

1. Index of Indirect Materials Handling $= \frac{a}{b}$

   where a = the sum of the distances a part moves automatically by conveyor and from machine to machine arranged in operation sequence without external materials handling.

   and b = the total actual distance a part moves via the production route from raw stores to finished stores.

A minor change in the definition of b should be included here. In tracing the path of a part over a production route, the part should be traced from the entrance to the layout area to the exit from the layout area. This permits a more general use of the index, as mentioned earlier in this section. Hence, b will be re-defined to read:

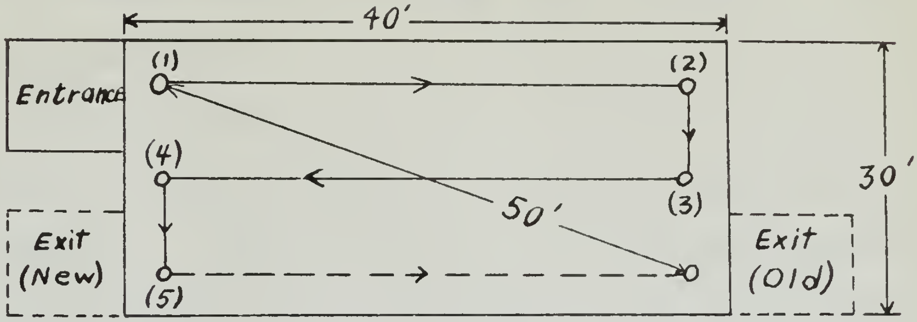
b = the total actual distance a part moves via the production route from the entrance to the layout area to the exit from the layout area.

2. Index of Direct Materials Handling $= \frac{c}{b}$

   where c = the direct line distance via the plant floor from raw stores to finished stores.

This index is difficult, if not oftentimes impossible, to

measure. It is defined as the length of a U, if the floor is U-shaped, or L, if L-shaped, etc. In many instances the flow of the part is from one building to another, one floor to another, or it may follow a particular flow in one room which will give a false value as an index. For example:



A certain product entered at point (1) and followed the path (2)-(3)-(4)-(5). It was then carried to the exit (old), a total distance of 150 feet. The direct line distance from the entrance to the exit (old) was 50 feet. This gave an index value for Direct Materials Handling of:

$$\frac{c}{b} = \frac{50'}{150'} = .33$$

In the revised layout the exit was relocated near point (5), where the production ended. Hence, the part traveled only a distance of 110 feet, but the direct line distance from the entrance to the exit (new) was reduced to 30 feet. This gave an index value for Direct Materials Handling of:

$$\frac{c}{b} = \frac{30'}{110'} = .27$$

This would indicate a less desirable situation rather than a better layout, which is actually the case.

For a continuous repetitive production this factor might be applied, if it were a direct, easily traced line flow from raw stores to finished stores. This has not been found to be the normally existing case in industry.

In lieu of Index #2, the following Index is proposed:

Index of Total Materials Handling = b

where b = the total actual distance a part moves via the production route from the entrance to the layout area to the exit from the layout area.

This value represents the exact distance required for a part or piece to travel during production. It is, in itself, a better measure of the efficiency with which the production route is laid out. There is no need for further complicating the index by forming a ratio, inasmuch as any plant or area, producing the same parts, can be more easily and accurately compared on the basis of this proposed value.

3. Index of Gravity Utilization = $\frac{d}{e}$

where d = the sum of the vertical distance gravity feed used.

and e = the total vertical distance up a part moves from raw stores to finished parts.

The Index of Gravity Utilization is designed to show the efficiency of gravity in returning to the main floor, parts lifted therefrom. There is some doubt as to the usefulness of this index in the evaluation of single-story plants. This conclusion is reached after obtaining very high values for a one-story plant which raised a part only a few feet and then regained this energy output completely by the force of gravity. In comparison, a multi-story plant which skillfully employed gravity in order to utilize a very large percentage of its energy expenditure, over several of the floors, would still have a lower value for this index. It is believed that this

index, to be of maximum value and to give the fairest comparisons for industrial use, should be limited to the evaluation of multi-story buildings.

The value of <u>e</u> should not be restricted to the total vertical distance <u>up</u> that a part moves. The same amount of energy is expended whether a part moves up or down by machine or human effort. Therefore, a doubled value of <u>e</u> should result if a part is moved up and then returned by machine or human effort. This is, in effect, a penalty for expending power when gravitational energy is available. Example: A part moves up by power conveyor a distance of 30 feet. It returns by power conveyor a distance of 10 feet, and by gravity the remaining distance of 20 feet.

Previous Analysis	Proposed Analysis
d = 20 feet	d = 20 feet
e = 30 feet	e = 30 feet + 10 feet
$\frac{d}{e} = \frac{20}{30} = .66$	$\frac{d}{e} = \frac{20}{40} = .50$

Therefore, it is proposed that this index be modified as follows:

Index of Gravity Utilization $= \frac{d}{e}$

where d = the sum of the vertical distance gravity feed is used in a multi-story plant.

and e = the total vertical distance up or down a part moves, involving machine or human effort, from the entrance to the layout area to the exit from the layout area, of a multi-story plant.

4. Prime Index of Automatic Machinery Loading $= \frac{f}{100g}$

where f = the sum of the percentages of machine down

time from all cases where the individual percentages of down time are equal to, or less than, 50% of the individual work cycles.

and g = the total number of operators on those machines.

This index was used successfully and required no change or modification.

5. Secondary Index of Automatic Machinery Loading = $\frac{h}{100g}$

where h = the sum of the percentages of machine down time from all cases where the individual percentages of down time are greater than 50% of individual work cycles.

This index was not evaluated. No situation presented itself, during the preparation of this paper, in which this index could be used. From the experience gained in using Index #4, it appears that this index, too, would be applicable without change or modification.

6. Index of Flexibility = $\frac{j}{k}$

where j = the number of machines capable of being moved to a new location in the production line in one working shift.

and k = the total number of machines in the production line.

This index is too restrictive. Many production lines have machines installed which perform no operation on the particular item flowing in the production line at a specified time. The flexibility of such machines would reflect no accurate indication as to the true flexibility of the layout, as pertains to the particular item under consideration.

It is recommended that Index #6 be separated into two indices; one to describe the flexibility as pertains to the <u>flow of the part</u> and the other, as pertains to the <u>utilization of men and machinery</u>. These proposed indices would be as follows:

(a) Index of Production Line Flexibility $= \frac{j_1}{k_1}$

where $j_1 =$ the number of machines or work stations performing operations on the part under consideration, so designed as to be capable of being moved to a new location in the same production line in one working shift.

and $k_1 =$ the total number of machines or work stations performing operations on the part under consideration, in the production line.

(b) Index of Work Station Flexibility $= \frac{j_2}{k_2}$

where $j_2 =$ the number of machines or work stations, within the area under consideration, so designed as to be capable of being moved to any other location in one working shift.

and $k_2 =$ the total number of machines or work stations within the area under consideration.

A concise meaning of two terms is important when using this index. It is proposed that these terms be defined as follows:

<u>Definition of Machine</u> - A non-portable device with a separate, or individual, power source.

<u>Definition of Work Station</u> - The area covered by the

tools, equipment, machines and in-process material, necessary to the performance of a given operation.

7. Index of Floor Area Loading Density = $\frac{\sum[(m+2)(n+2)+p]}{q-r}$

where m = extreme machine length in feet

n = extreme machine width in feet

p = operator work area in square feet

q = total plant floor area in square feet

and r = total aisle area in square feet.

In this index the definition of machine should be consistent with that used in Index #6. "Work station" should also be used in this index since a work station does consist of useful production area. The following meaning is proposed for p:

p = the total work area normally required by an operator in the performance of his job.

And in accordance with the assumption that layout is not only concerned with the entire plant, but lesser areas as well, q shall be defined as follows:

q = total layout floor area in square feet.

It should be emphasized that the areas occupied by the machines, work stations and operators may be totally independent of each other. That is, a productive work area may consist of machines or work stations operated by workers, machines operating independently, or workers operating independently.

The denominator does not correctly represent the total area available to production. From experience in all the plants investigated, it has been found that the denominator represents storage area as well as direct production area. In

order to make this index more definite as to efficient use of plant floor area for production use only, the following value is introduced:

u = total floor area, in square feet, occupied by temporary or controlled storage of material, or tools and equipment required to modify this material.

Therefore, it is proposed to re-write the formula as follows:

$$\text{Index of Floor Area Loading Density} = \frac{\sum\left[(m+2)(n+2)+p\right]}{q-(r+u)}$$

This index will now give a more accurate indication of the efficiency with which productive floor space is utilized.

8. $\text{Index of Aisle Wastage} = \dfrac{q-r}{q}$

where q = total layout floor area

and r = total aisle area.

This index has been defined as representing the total plant floor area available for placement of production machinery. As indicated under Index #7, this area would be available for both production and storage. The title of the index has created considerable question in application. Increased aisle area is not necessarily increased waste area. Intangible factors such as increased safety, less crowding, etc., might be the result of a so-called increase in Aisle Wastage. It is proposed that this index be changed as follows:

$$\text{Index of Aisle Space} = \frac{r}{q}$$

This index now gives a true indication of over-all utilization of layout floor area for aisles. An increase or decrease in aisle area is readily reflected by an increase or decrease in this proposed index. The particular manufacturing conditions encountered will determine whether a high or low value of this

index is desirable.

9. Index of Time = $\frac{s}{t}$

where s = the sum of the standard times for all operations on a part.

and t = the total standard times for the part, raw stores to finished stores including handling time and time in banks.

This index measures the time efficiency with which a part traverses the production process. In actual measurements in industrial plants, it has been extremely difficult, or, in most cases, impossible to measure this index accurately. The numerator is simple and easy to obtain. However, the denominator is extremely variable and subject to pure estimation in almost every instance. It has repeatedly been brought to this author's attention that methods, not plant layout, is the controlling factor in this index. It is conceivable that plant layout could affect the storage or delay in the production or handling of part. However, it is the responsibility of proper methods to obtain the optimum value of this index with the given plant layout. In view of the fact that this index is controlled by methods, rather than by plant layout, it is recommended that it be eliminated as a plant layout index.

10. Index of Inventory = $\frac{x}{y}$

where x = rate of production

and y = index of time.

This index shows the number of production units planned for the production line at one time. Inasmuch as y is equal to the Index of Time, it will be apparent that this index is also

a function of methods, rather than plant layout. Although it is recognized that production rate may be a direct function of proper plant layout, it is felt that for a given plant layout the production rate is more often the result of other factors, methods being one of the most prominent.

Further, the Index of Time, in measurements obtained thus far, has resulted in extremely small values. When used as the denominator, in the Index of Inventory, a very large number results. The slightest variation in the rate of production produces such a fluctuation in this index that it is of little, if any, value, either as a direct measure, comparison, or reliable indication of inventory

For the above reasons, it is recommended that the Index of Inventory be eliminated as a useful measure of plant layout.

PROPOSAL OF ADDITIONAL CRITERIA

During the evaluation of the previously proposed criteria, by their employment in actual plant layouts, it was felt that certain areas of the physical-plant study were not being completely analyzed. The following additional indices are proposed to cover these areas:

1. Index of Storage Space $= \frac{q-u}{q}$

where q = total layout floor area

and u = total floor area occupied by temporary or controlled storage of material, or tools and equipment required to modify this material.

This index is proposed as an adjunct to the Index of Floor Area Loading Density, where u retains the same meaning. This index gives a true indication of over-all utilization of layout floor area for storage of in-process materials, or the tools and equipment required to modify this material. An increase or decrease in storage area is readily reflected in this index.

2. Index of Storage Volume Utilization $= \frac{v}{w}$

where v = volume occupied by raw materials or finished goods at the normal maximum attainable level of storage.

and w = total volume available for storage of raw materials or finished goods.

This index would measure the cubage utilization of storage or warehouse spaces, such as Receiving and Shipping. This index

would also be a measure of proper packaging, palletizing or materials handling, as pertains to storage systems.

The above criteria, as proposed, are not considered to be exhaustive in the field of plant layout evaluation. The need for these particular indices was evident, however, from a study of those plants evaluated in this paper. Other indices were developed, but finally rejected, because they were not measures of layout alone. Attempting to confine the field of study to those factors affecting the physical-plant only will naturally place a more restrictive limit on the variety of criteria which may be proposed.

PROCEDURE FOR EVALUATION AND VALIDATION OF CRITERIA

In attempting to properly evaluate the indices of physical-plant utilization it was necessary to consider those areas which offered the most diversified means of analysis. It was also considered a pre-requisite that such an analysis should take place under closely controlled conditions of accuracy and should be as close an approximation to actual situations as possible.

Since plant layouts vary according to the specific items manufactured, processes required, and many other factors, it was necessary to find some criterion of improved plant layout in order to validate these indices. This was accomplished by internal validation. That is, only plants manufacturing the same item under two conditions of plant layout, both initial and revised, were evaluated. The criterion of improvement was established either quantitatively, such as increased production or savings; or qualitatively, such as increased safety or improved inspection.

Of the methods considered, the choice was narrowed to the three which seemed to most nearly meet the required standards. The three methods which were considered in performing the evaluation were:

(1) To make a survey of the various technical journals and publications in the light of their applicability to the appraisal of the indices. To do this, it would be necessary to resolve those articles dealing only with the "before and after" aspects of layout.

(2) To distribute questionnaire-type lists to the

Industrial Engineering Departments of those plants having records of revised layouts. These lists would seek the necessary information required to properly evaluate the indices.

(3) To visit various plants for the purpose of making the necessary physical measurements of existing or proposed layouts, as well as making detailed studies of available files, records, blueprints or template layouts.

The first method failed of selection after an intensive survey of technical journals and publications, covering the period from 1940 to 1950, failed to produce sufficient data for an accurate appraisal of any one of the indices. The large majority of these articles were written in vague generalities, and illustrated by photographs, rather than describing the previous and revised layouts in terms of actual facts and drawings.

The second method failed of selection because of the impractical aspect of requiring a large amount of data-gathering to be done by plant personnel. After developing a tentative list of the questions required, in order to properly evaluate the indices, it was felt that submission of the list would be an imposition on those engineering personnel involved in bringing it to completion

The last method was chosen for evaluation of the indices. It was felt that applied measurements in the physical-plant would certainly give the closest approximation to actual situations. The accuracy of calculations was dependent, to some extent, on records and models. However, every effort was made to assure complete results and the maintenance of the indices as functions of physical-plant utilization alone.

For the evaluation, five factories in the Central Indiana area were chosen for study. These factories were selected for their adequate layout revisions and for the heterogeneous selection of manufactured items which they offered. This diversity of products was necessary from the standpoint of the layout analysis.

Over twenty plants were originally considered for the validation of these criteria. Of these plants, several were to prove unavailable, due either to government classified work or to processes which involved trade secrets. Of the remaining plants which could not be used, the difficulties encountered fell into two general classifications:

(1) The plant did not have adequate files or information regarding the previous or revised layout; or the author was not allowed sufficient freedom to obtain enough complete information to present a valid report.

(2) The criteria governing the previous and revised layouts were not functions of layout alone, but were also functions of better processes or methods.

Thus, the final selection of plants was based on a combination of diversified products and layouts, adequate records, freedom of access, and criteria of revisions based only on pure physical-plant utilization.

APPLICATION OF CRITERIA TO EXISTING PLANTS

As stated in the previous section, the criteria of physical-plant utilization were evaluated in five different plants. The results of these evaluations are outlined in this section.

The evaluation of each plant will be preceded by a plan view of the layout area concerned. This plan view will consist of two figures; one, representing the previous layout area, and the other, representing the revised layout area.

Following this, a brief summary of the plant operations, products and background will be presented. The criterion of improvement of the revised layout will be included.

Each index will then be evaluated under both conditions of layout. Pertinent facts and recommendations relative to the applicability of the indices to each layout area will be included.

Only the final values of each of the letters or symbols will be included in these studies. The large amount of computation required, in arriving at these values, would only serve to confuse the analysis and would add little to the understanding of the subject.

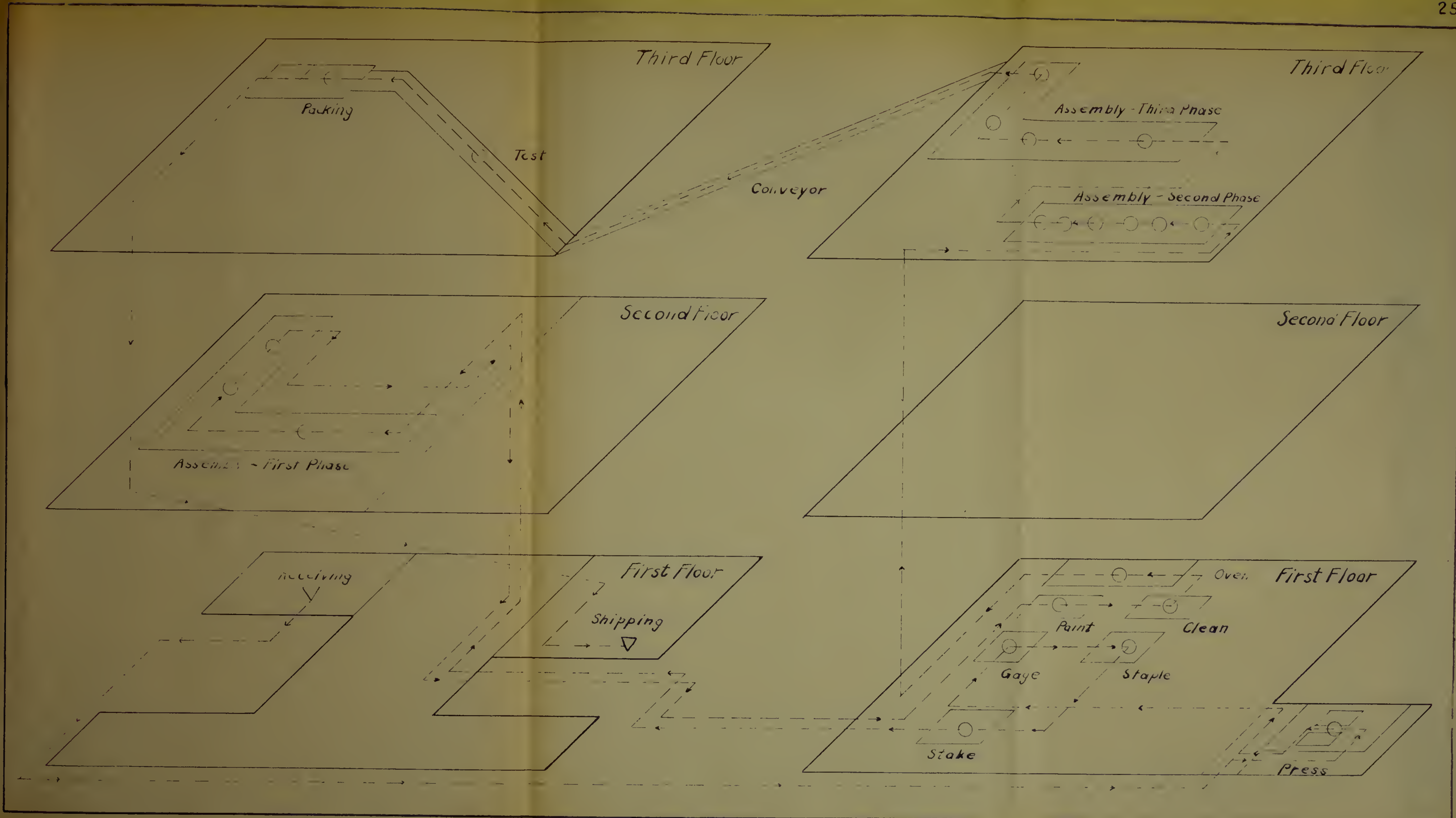


Fig. 1a - Initial Layout, Duncan Electric Company

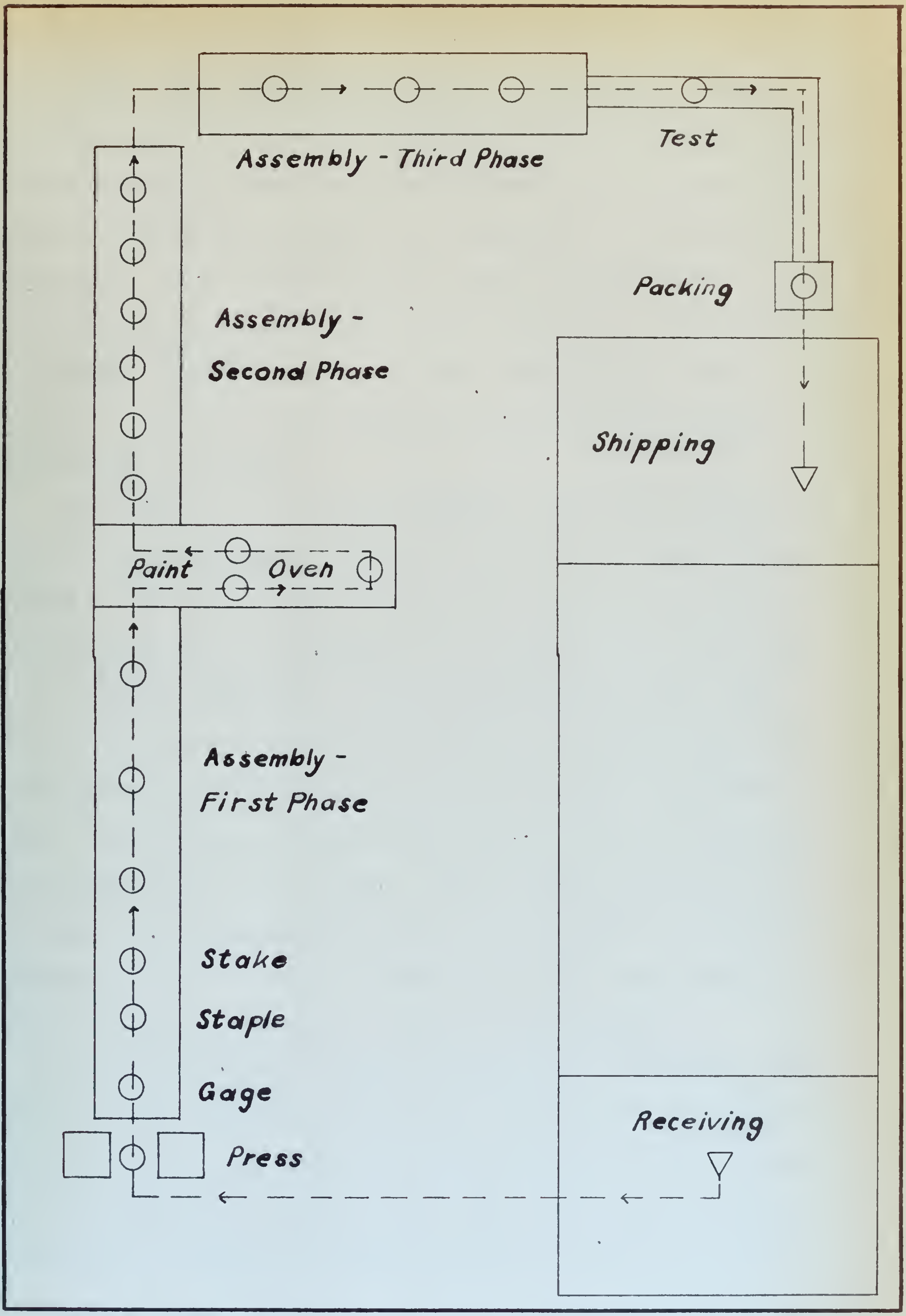


Fig. 1b - Revised Layout, Duncan Electric Company

I The Duncan Electric Company - - Lafayette, Indiana

In this plant the electromagnet E coil core was traced from its start in the Receiving Department, as coiled steel strip, until it was shipped as a component of a Standard Wattmeter. While undergoing its various operations the core followed a path which included four floors and three separate buildings. The old plant, in this case, was in a very decrepit condition and at least one portion of a building was already condemned.

The new plant was not to commence production until too late for a performance report to be included in this thesis. However, the same machinery required to produce this particular core in the old plant was to be moved to the new plant with only one exception - a new painting and drying oven. Enough performance data was available to analyze this particular machine in its relation to the planned production line. The new plant layout was analyzed from an elaborate three-dimensional scale model. While expected production and performance figures were necessarily based on careful estimates, even a cursory inspection of the two layouts would indicate a tremendous over-all improvement.

Beyond these improvements a production increase of 25% is anticipated for this product, as a result of this layout change. It is to be noted that other than the above change in the painting and drying oven, there have been no changes in methods throughout the manufacture of this part in the

new plant. This further verifies the fact that the benefits to be derived from the new plant, at least with respect to this product, are due to the new layout alone.

<u>Plant Layout Evaluation of the Duncan Electric Company</u>

1. Index of Indirect Materials Handling $= \frac{a}{b}$

Initial Layout	Revised Layout
a = 504 ft.	a = 255 ft.
b = 2761 ft.	b = 560 ft.
$\frac{a}{b} = .183$	$\frac{a}{b} = .456$

The reduction in the total actual distance the part moves is probably the greatest improvement in the plant. Although it appears that the conveyor usage has actually decreased in the new plant (item <u>a</u>) it should be stated that over 400 ft. of the conveyer in the old plant is used for transportation purposes only - whereas all conveyors in the new plant will be utilized for operational sequences.

2. Index of Direct Materials Handling $= \frac{c}{b}$

Initial Layout	Revised Layout
c = 1444 ft.	c = 425 ft.
b = 2761 ft.	b = 560 ft.
$\frac{c}{b} = .523$	$\frac{c}{b} = .76$

Although this indicates an improvement in the layout of the production route, it does not give a true picture, when comparing the ratios of the old and new layouts. The difficulty lies in actually measuring the value of <u>c</u>. As stated earlier in this paper, the best index of the Direct Materials Handling

would be item b itself. The value of b shows the improvement in its true perspective.

3. Index of Gravity Utilization $= \frac{d}{e}$

Initial Layout	Revised Layout
d = 22 ft.	d = 0
e = 94 ft.	e = 0
$\frac{d}{e}$ = .234	$\frac{d}{e}$ = One Floor

Inasmuch as the new plant is situated wholly on one floor, and since this particular part is moved neither up nor down during production, this index does not apply. However, in the old plant there is an opportunity for improvement, as evidenced by this index. It is safe to assume that there will be an increase in efficiency in maintaining production on one level, in this instance, inasmuch as some expended energy in elevating the part, in the old layout, is never recovered.

4. Index of Flexibility $= \frac{j}{k}$

Initial Layout	Revised Layout
j = 10	j = 10
k = 17	k = 16
$\frac{j}{k}$ = .588	$\frac{j}{k}$ = .625

No actual improvement in flexibility of equipment was contemplated inasmuch as the same machines are to be used in the new plant that were previously used in the old plant. The change in k is due to the combining of two permanent machines, paint drier and oven, into one permanent conveyor

type machine.

5. Index of Floor Area Loading Density $= \dfrac{\sum[(m+2)(n+2)+p]}{q-r}$

Initial Layout	Revised Layout
$\sum = 1253$ sq.ft.	$\sum = 1533$ sq.ft
$q = 6630$ sq.ft.	$q = 10{,}200$ sq.ft.
$r = 3514$ sq.ft.	$r = 2450$ sq.ft.
$\dfrac{\sum}{q-r} = .403$	$\dfrac{\sum}{q-r} = .198$

This may or may not be a true measure. The value of q for the old plant is questionable. As stated earlier, this is a case in which it is extremely difficult to measure the exact amount of floor area designated for the production of this one part. Many other part pieces during processing overlapped the production area used by this part thus making the accurate measurement of q doubtful. Inasmuch as the new plant layout has one area designated for the production of this part alone, the value of q obtained for that plant is much more accurate. This index, when following the flow of a part, is believed to be unreliable.

6. Index of Aisle Wastage $= \dfrac{q-r}{q}$

Initial Layout	Revised Layout
$q = 6630$ $r = 3514$	$q = 10{,}200$ $r = 2{,}450$
$\dfrac{q-r}{q} = .472$	$\dfrac{q-r}{q} = .758$

Although this index does reflect a better utilization of plant floor area, it cannot be considered too accurate due

to the questionable value of $\underline{q}$ in the old plant. Other shortcomings in this index have been discussed in earlier pages.

7. Index of Time $= \frac{s}{t}$

Initial Layout	Revised Layout
s = 16.216 min.	s = 15.976 min.
t =	t =

This Index has been discarded. (see previous comments). The value of $\underline{s}$ is easily and accurately obtained and, in itself, would at least be a good measure of Methods. However, inasmuch as the value of $\underline{t}$ is almost impossible to measure in the majority of instances, it is felt that this proposed index would be of little, if any, value regardless of the accuracy of $\underline{s}$. The value of $\underline{t}$ is dependent on such factors as sales, methods, material availability and scheduling, to mention only a few. For example, large quantities of a component of a product may be manufactured and stored, depending on availability of material at a particular time. Or oftentimes a product is stopped in the middle of the manufacturing cycle to allow the introduction of a different product - this is usually dependent on sales systems and the market. Therefore, due to the fact that so many variables, independent of the plant layout, are controlling factors in this index and, under certain conditions, result in values of $\underline{t}$ ranging from minutes to months, it has been decided to eliminate this Index as a means of measuring plant layouts.

8. Index of Inventory $= \frac{x}{y}$

This index failed as a measure of Inventory. This was due not only to the indeterminate value of the Index of Time but to the variable quantity of production as well. It is conceivable that in some plants a fixed production rate might be established and maintained, but in the majority of factories, as in this one, the production rate depends on factors such as the Market, Sales, Material and Labor. In this plant, the production rate varied from day to day. Any attempt at estimating, averaging or generalizing the production rate under the old or new layout would only result in a meaningless value for this index.

9. Index of Storage Volume Utilization $= \frac{v}{w}$

<u>Receiving</u>

Initial Layout	Revised Layout
$v = 15316$ $w = 34130$ $\frac{v}{w} = .449$	$\frac{v}{w} = .85\ (\pm .05)$

<u>Shipping</u>

Initial Layout	Revised Layout
$v = 5230$ $w = 15100$ $\frac{v}{w} = .346$	$\frac{v}{w} = .85\ (\pm .05)$

The present shipping and receiving storage spaces are poor examples of optimum space utilization. The spaces provided for these storages are disconnected and sometimes fairly inaccessible. The limitation in use of vertical space in Shipping is the stacking height of the corrugated cardboard boxes. At a height of approximately 8' the boxes begin to

crush and lean, precipitating a hazardous situation. A lift truck is available but is utilized mainly for hauling, rather than stacking. Use of the proper type pallets throughout these storage spaces would result in a tremendous increase in present storage capacity. It is interesting to note that the lack of sufficient storage space is a problem confronting the responsible personnel at the present plant, yet so much valuable storage volume remains unused.

In the new plant all shipping and receiving storage spaces will be coherent. Palletizing, skids, mechanical and hand lift trucks and hoists will be used. The stacking height of merchandise will be limited only by overhead obstructions. The expected volumetric utilization of these assigned storage spaces will reach approximately 85%. The Index of Storage Volume Utilization readily reflects the use of storage space in both the old and new plants.

II U.S. Naval Ordnance Plant, Indianapolis, Indiana

In this plant two areas of layout were analyzed. These areas were chosen for two reasons; one was that the areas varied in size from a department layout to a division layout, second, the areas represented different types of industrial situations, which would better serve to test the applicability of the indices which were to be evaluated.

The layouts and re-layouts of the particular areas chosen for study were carefully recorded in plant layout files. All required information was gathered either from these files, from the Methods Department or from actual measurements on the floor.

In NOPI an attempt was made to evaluate the indices which best described the proper layout with respect to the utilization of machinery and men.

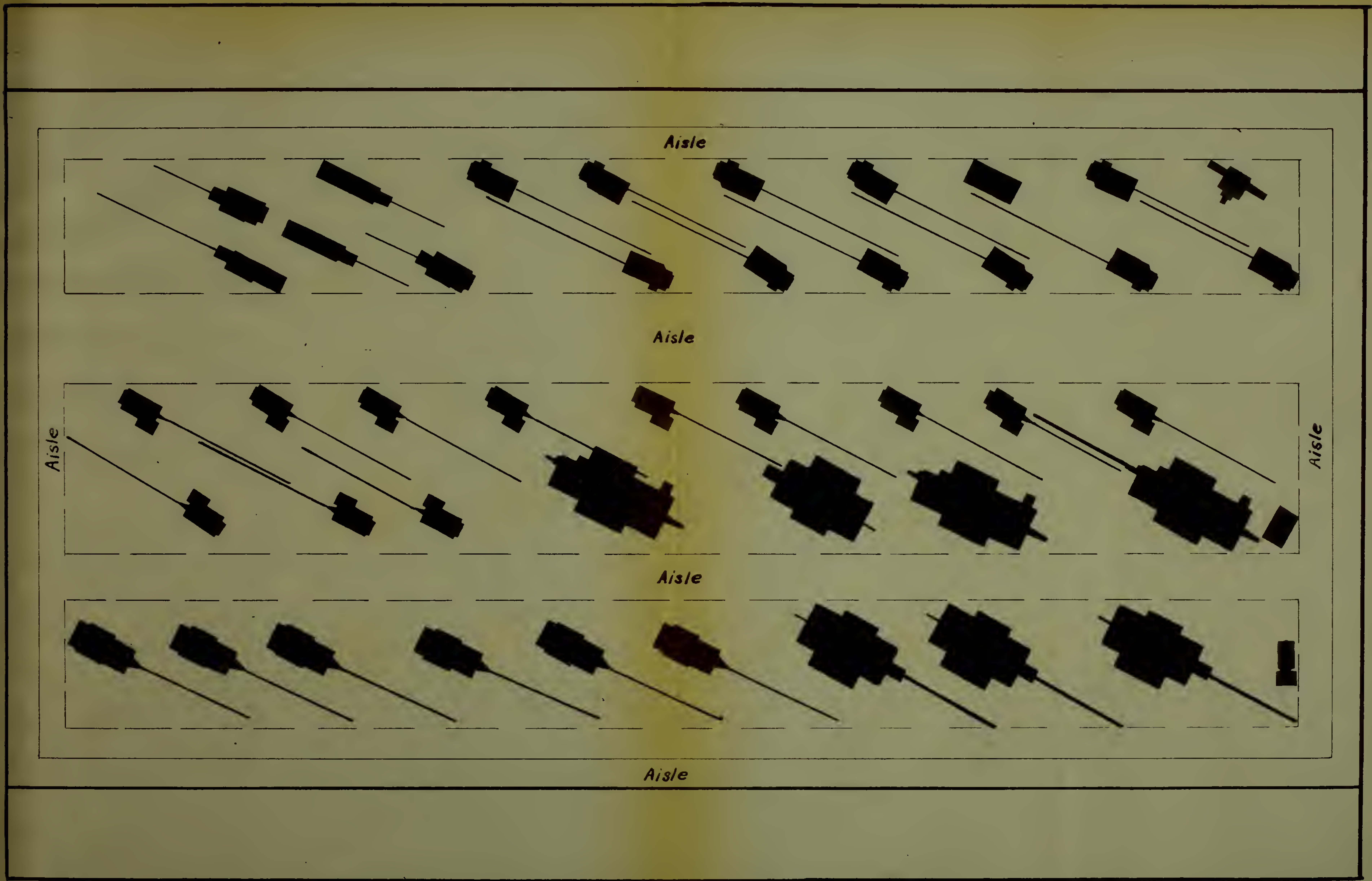


Fig. 2a - Initial Layout, Machine Department, NOPI

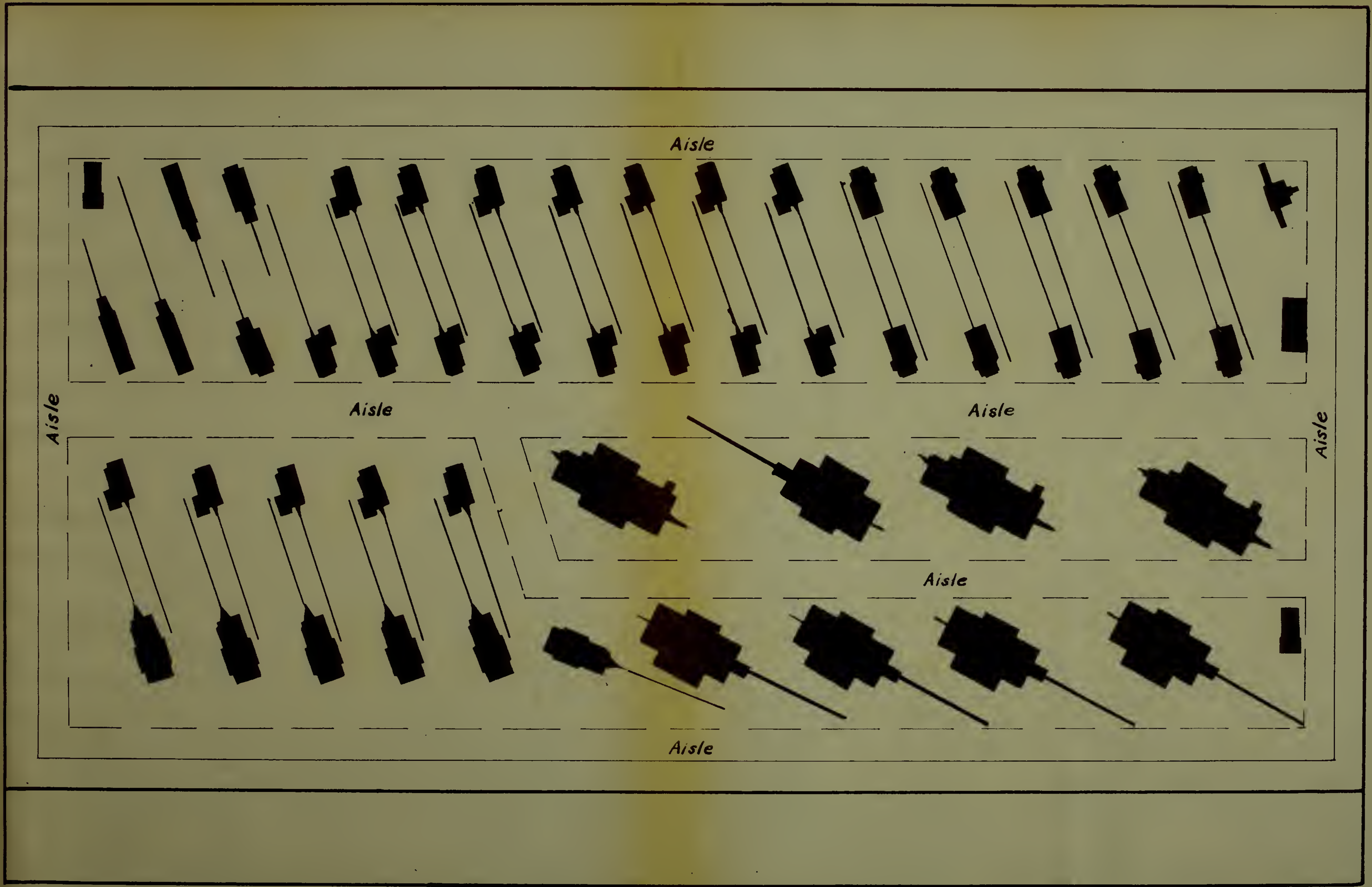


Fig. 2b - Revised Layout, Machine Department, NCPI

Layout Evaluation of the Automatic Screw Machine Department

The major advantages cited for the new layout, as compared with the old, were:

(1) A resulting higher ratio of machines per man.

(2) More productive machinery located in the same area.

(3) An increase of approximately 11% in work unloaded in this department the first three months after the new layout was installed, as compared to the last three months of the previous layout.

1. Prime Index of Automatic Machinery Loading $= \frac{f}{100g}$

Initial Layout	Revised Layout
$f = 45 \times 20$	$f = 53 \times 20$
$g = 12$	$g = 12$
$\frac{f}{100g} = .75$	$\frac{f}{100g} = .88$

This department maintained a "down time" figure of very close to 20%, on an average, for the machines located therein. The increase in this index is due to the increase in the number of automatic machines, while retaining the same number of operators and the same "down time" percentage. This index is, therefore, a measure of the grouping efficiency of these multi-machine operations.

2. Secondary Index of Automatic Machinery Loading $= \frac{h}{100g}$

This index does not apply inasmuch as the percentage of down-time for all automatic machines in this department was maintained at approximately 20%.

3. Index of Work Station Flexibility = $\frac{j_2}{k_2}$

Initial Layout	Revised Layout
$j_2 = 38$	$j_2 = 45$
$k_2 = 45$	$k_2 = 53$
$\frac{j_2}{k_2} = .84$	$\frac{j_2}{k_2} = .85$

In the re-layout of this area eight (8) more automatic machines were added. Of these, seven (7) were so designed as to be capable of movement to any other location in one working shift. Although the difference between the two layouts in this respect is slight, this difference is measureable and is reflected in this index.

4. Index of Floor Area Loading Density = $\frac{\Sigma[(m+2)(n+2)+p]}{q-r}$

Initial Layout	Revised Layout
$\Sigma = 2507$	$\Sigma = 2874$
$q = 5775$	$q = 5775$
$r = 2395$	$r = 1871$
$\frac{\Sigma}{q-r} = .743$	$\frac{\Sigma}{q-r} = .736$

The fact that this index decreases in value, although the same area contains more machines under the new layout, would seem to indicate an inconsistency somewhere in the data presented. The answer seems to lie in the method by which the machines were combined in the new layout. A brief study of the layouts will show that previous surplus space around certain machines was eliminated by a unique combination of "end to end" placement. The fact that aisle area was decreased allowed some extra room for the installation of productive equipment. Since this index does not show a

measurable increase in the floor loading density, it might be assumed that either the Index is of little value when used alone, in this case, or a very skillful re-layout was employed. It is the considered opinion of this writer that both conditions exist.

5. Index of Aisle Space $= \frac{r}{q}$

Initial Layout	Revised Layout
$r = 2395$	$r = 1871$
$q = 5775$	$q = 5775$
$\frac{r}{q} = .42$	$\frac{r}{q} = .32$

This index does show that the floor area available for active production machinery has been increased. Although the aisle space has been decreased in the new layout, it has been so judiciously arranged that actual access of material to and from the machines, especially the heavy Cleveland Automatics, has been greatly facilitated.

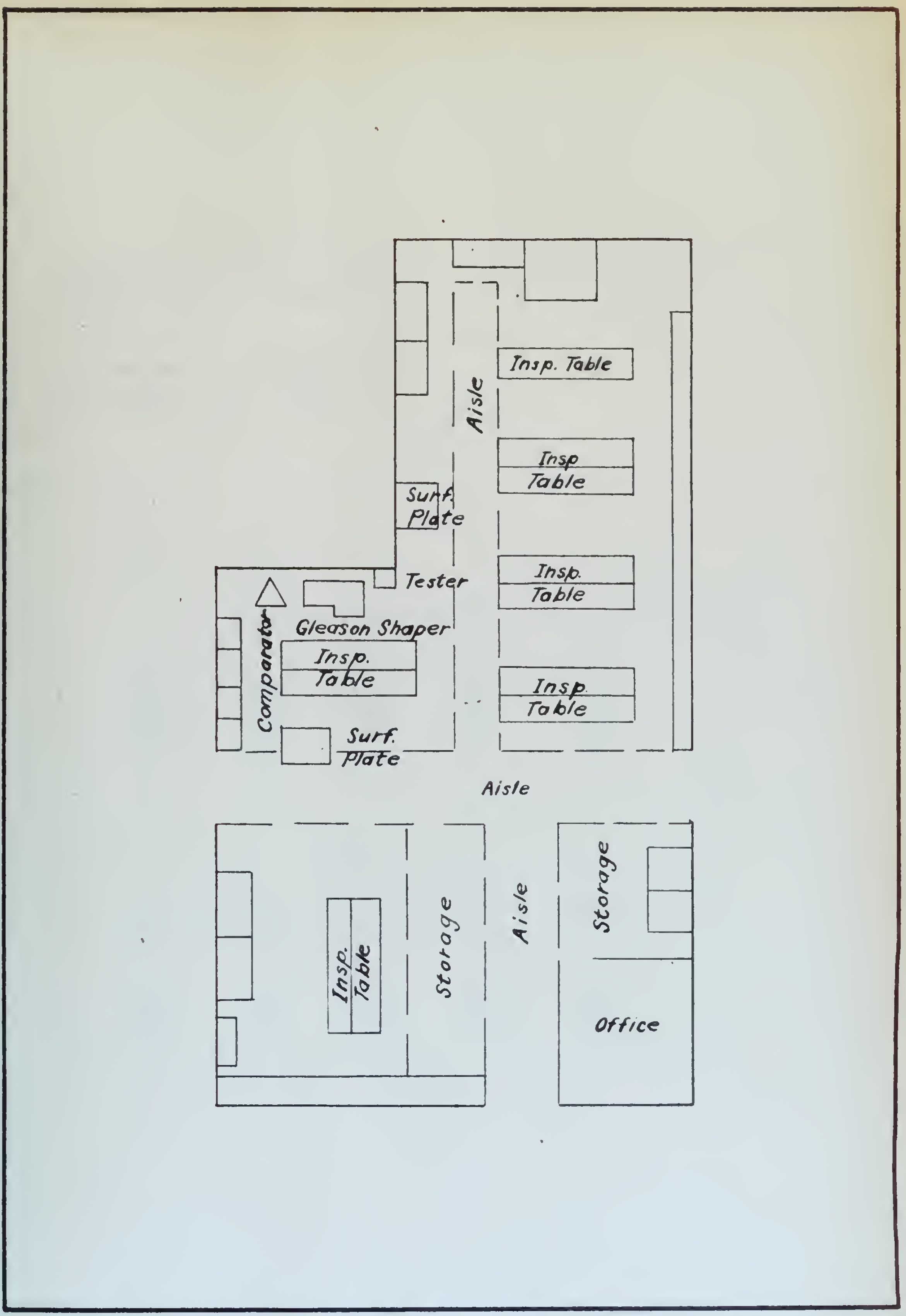


Fig. 3a - Initial Layout, Inspection Div., NOPI

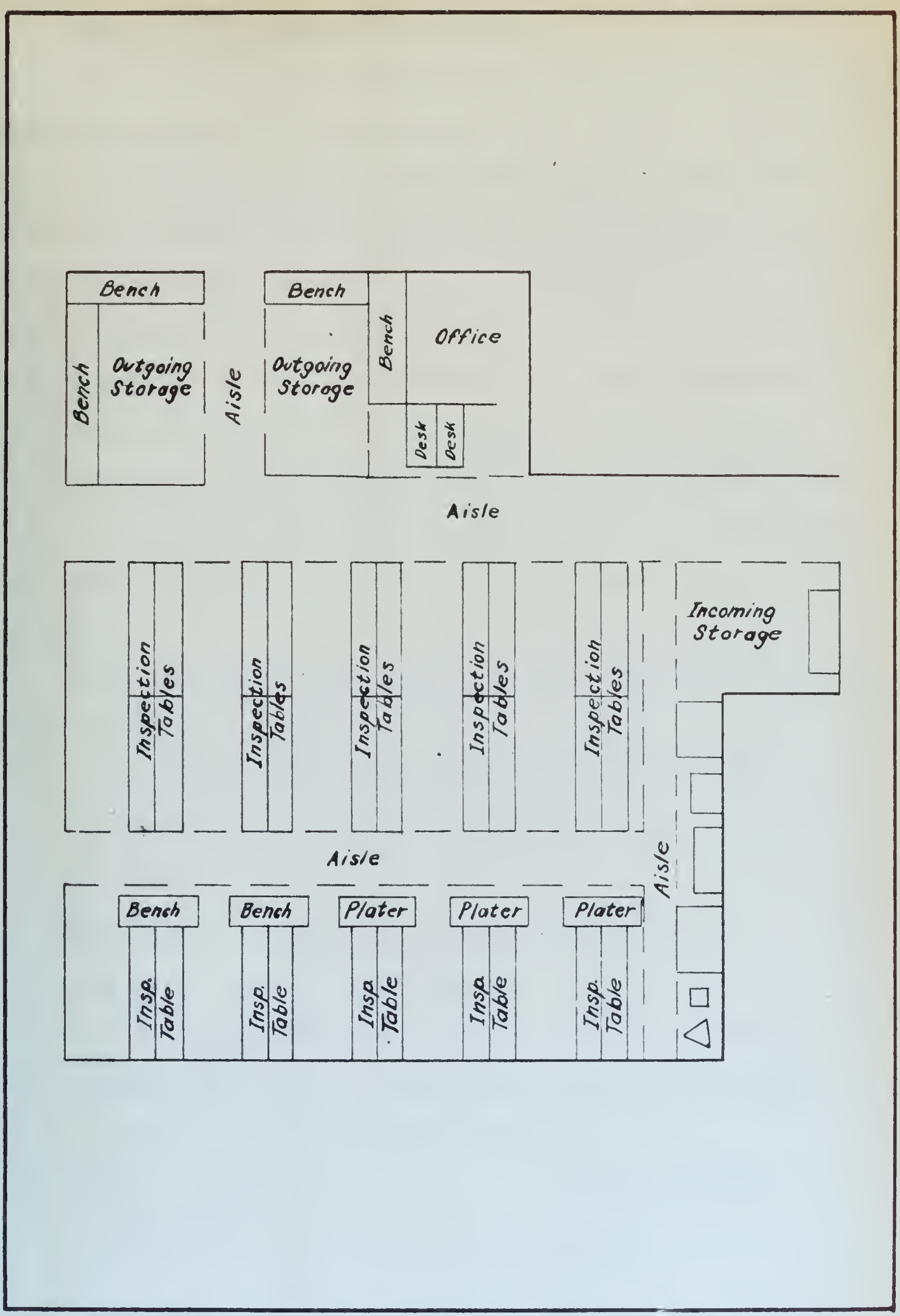


Fig. 3b - Revised Layout, Inspection Div., NOPI

NOPI - Parts Inspection Division

This Division encompassed a work area in which the work stations consisted of operators at test benches. The material to be tested, usually manufactured parts, was first placed in the incoming storage space. From there it traveled to various inspectors at their test benches. Certain tests required the operator to utilize the special equipment available elsewhere in the inspection area. Upon completion of the inspection the material was taken to the outgoing storage space. This layout, due to the complexity of the different parts tested and indeterminate routes traveled, was best analyzed as to the optimum utilization of men and machinery.

The major advantages cited for the new layout, as compared with the old, were:

(1) A better flow of material under inspection.

(2) More inspections per operator per unit of floor space.

(3) Increased number of inspection facilities.

(4) More convenient arrangement of the inspection equipment from the viewpoint of the inspectors.

Layout Evaluation of the Parts Inspection Division

1. Index of Work Station Flexibility = $\frac{j_2}{k_2}$

Initial Layout	Revised Layout
$j_2 = 10$	$j_2 = 21$
$k_2 = 10$	$k_2 = 21$
$\frac{j_2}{k_2} = 1.0$	$\frac{j_2}{k_2} = 1.0$

In both cases the work stations were merely test benches or testing devices with standard electrical attachments.

2. Index of Floor Area Loading Density $= \dfrac{\Sigma[(m+2)(n+2)+p]}{q-(r+u)}$

Initial Layout	Revised Layout
$\Sigma = 1020$	$\Sigma = 2320$
$q = 2510$	$q = 3941$
$r = 453$	$r = 756$
$u = 232$	$u = 438$
$\dfrac{\Sigma}{q-(r+u)} = .56$	$\dfrac{\Sigma}{q-(r+u)} = .84$

This index shows a decided advantage obtained in the new layout in regards to maximum use of the floor area for productive effort. This increase is due to a better layout of the work stations, and related equipment. This fact is readily indicated by this index, even though the new layout required a proportionately greater amount of total floor area, aisle area and storage area.

3. Index of Aisle Space $= \dfrac{r}{q}$

Initial Layout	Revised Layout
$r = 453$	$r = 756$
$q = 2510$	$q = 3941$
$\dfrac{r}{q} = .18$	$\dfrac{r}{q} = .19$

This index shows that some aisle space was gained in the new layout. In relation to the increase in the Floor Density Loading, this increase in aisle space is not detrimental. The real saving in this re-layout stems from the re-arrangement of the work stations. This index might point out an area for even further improvement in the layout.

4. Index of Storage Space $= \frac{q-u}{q}$

Initial Layout	Revised Layout
$u = 232$	$u = 438$
$q = 2510$	$q = 3941$
$\frac{q-u}{q} = .91$	$\frac{q-u}{q} = .89$

The Storage Area has also been increased proportionately. The same remarks apply as did those pertaining to the Index of Aisle Space. All waste space, in the old layout was carefully utilized in the new arrangement to provide either operator work space, aisle space or storage space. An examination of the layout diagrams will show how waste area at the ends of benches, around the cabinets and test tables, and in corners, was eliminated.

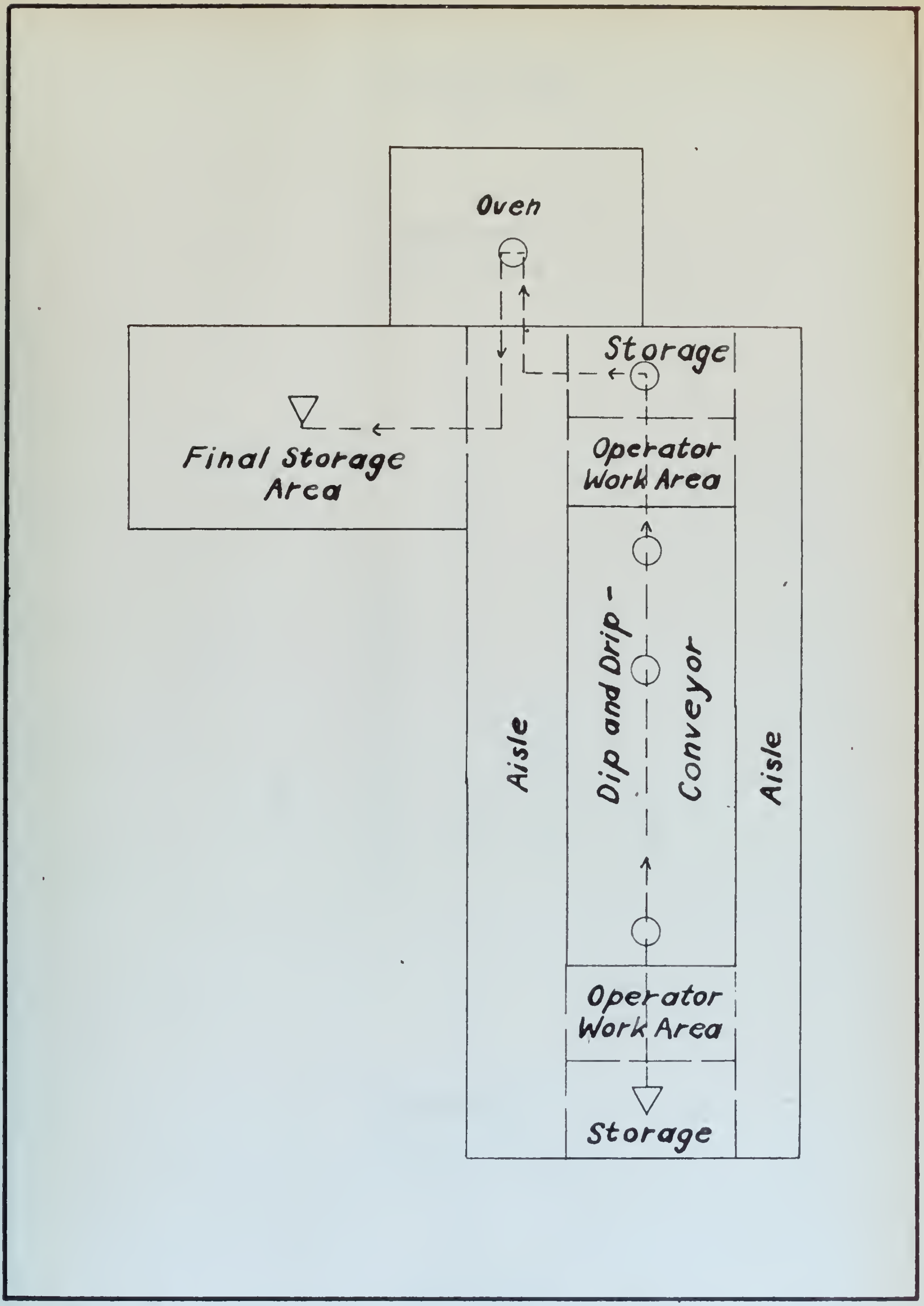


Fig. 4a - Initial Layout, Peerless Wire Co.

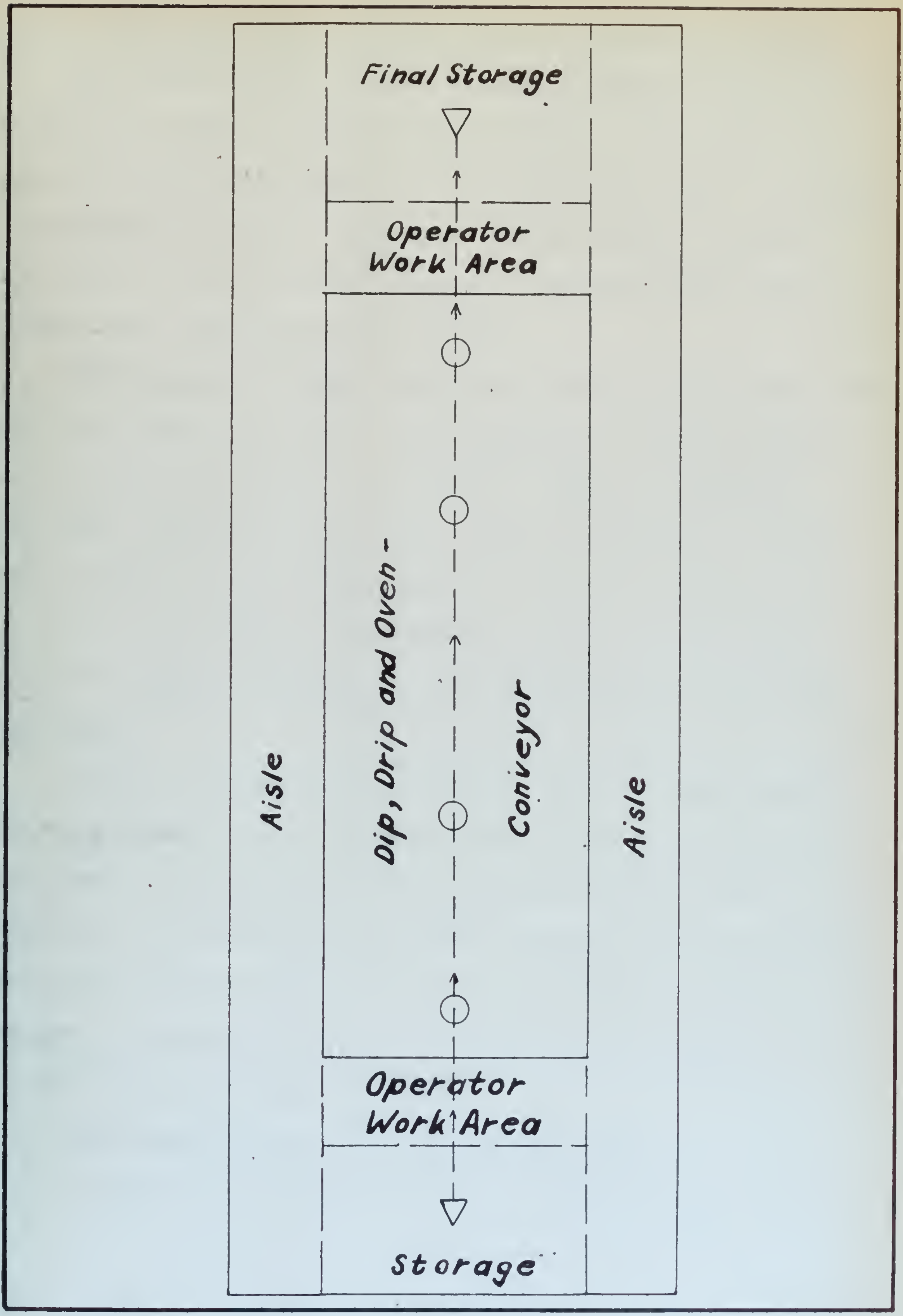


Fig. 4b-Final Layout, Peerless Wire Co.

III Peerless Wire Products, Inc., Lafayette, Indiana

The Peerless Wire Products Company manufactures many sizes and shapes of refrigerator shelves. The area analyzed herein consisted of the Enamel Division. Basically, the process evaluated consisted of dipping the finished shelves in a clear enamel solution, removing the excess enamel, and then drying the shelves.

Fortunately, in this case, both the old layout and the new layout were available for evaluation, the old layout still being retained in the event of further expansion. Accurate information in files, plus the necessary actual measurements on the floor, gave a reliable analysis of this Division. This evaluation was based on the actual flow of the parts, as well as the utilization of men and machinery.

Besides the qualitative criteria of increased safety, the comparison of the new layout with the old is based on the quantitative criteria of production and man power. In this case the production rate was increased from 500 pieces per hour to 1000 pieces per hour, an increase of 100%. The number of operators required was reduced from three to two, a reduction in personnel of 33%.

Layout Evaluation of the Enamel Division

1. Index of Indirect Materials Handling $= \frac{a}{b}$

Initial Layout	Revised Layout
$a = 30$	$a = 105$
$b = 65$	$b = 126$
$\frac{a}{b} = .46$	$\frac{a}{b} = .83$

The old method provided a conveyor only for the initial dipping of the part and with enough carrying distance to allow the part to finish dripping excess enamel before being removed to the oven. The conveyor in the new layout provided for the dipping and dripping operations but also was extended to provide for the oven drying of the parts. Although this is essentially a change in methods, it is so readily transformed into a better layout that it might be considered essentially a layout change. Here again, the dividing line is hard to define. In any event, this index does show a decided improvement in Indirect Materials Handling.

2. Index of Total Materials Handling $= b$

Initial Layout	Revised Layout
$b = 65$	$b = 126$

This index shows that the part piece is required to travel over twice the distance in the new layout as was required by the old layout. It must be remembered that the part is in continual motion during the drying operation in the new layout. The increased distance traveled by the part was the one concession made in order to obtain the other numerous advantages of the new layout. The index does readily indicate that the total material handling distance has been

increased.

3. Index of Production Line Flexibility $= \frac{j_1}{k_1}$

Initial Layout

$j_1 = 0$
$k_1 = 2$

$\frac{j_1}{k_1} = 0$

Revised Layout

$j_1 = 0$
$k_1 = 1$

$\frac{j_1}{k_1} = 0$

In conformance with the previous definitions of machine and work station it is noted that the devices and conveyors which perform the dipping, dripping, handling and drying operations might each be treated as an individual machine. In this instance the old layout was considered to consist of two machines; that is, the dipping, dripping and handling mechanism was considered as one machine and the drying oven as another. In the new layout these operations were combined into one inseparable work station. However, in this re-lay-out, since none of the machines were designed so as to be capable of being moved to a new location, this index reflects no actual change in the flexibility of the production line.

4. Index of Floor Area Loading Density $= \frac{\Sigma[(m+2)(n+2)+p]}{q-(r+u)}$

Initial Layout

$\Sigma = 303$
$q = 648$
$r = 141$
$u = 190$

$\frac{\Sigma}{q-(r+u)} = .95$

Revised Layout

$\Sigma = 1231$
$q = 1890$
$r = 756$
$u = 135$

$\frac{\Sigma}{q-(r+u)} = .90$

This index shows a decrease in the utilization of space for

production equipment. This decrease is slight and is attributed to the three-foot wide repair accessibility area along side the production line. A reduction in the width to $2\frac{1}{2}$ feet, as in the old layout, would have given an unchanged value to this index. Here, again, a more accurate picture of the new layout is obtained if this index is weighed in conjunction with the two following indices.

5. Index of Aisle Space $= \frac{r}{q}$

Initial Layout	Revised Layout
$q = 648$	$q = 6890$
$r = 141$	$r = 756$
$\frac{r}{q} = .22$	$\frac{r}{q} = .11$

An aisle must have some minimum width dependent upon its intended usage. In this case both the old and new layouts required an access aisle of a three-foot width. This aisle, when used to service a smaller machine, work station, or work area, as it does in the old layout, bears a considerably higher ratio of non-productive area to productive area than it does when serving a proportionately larger area, as exemplified by the new layout. For this reason the minimum number of aisles, consistent with usage requirements of a layout, should be a definite goal in the planning of a good layout. This index is a good measure of the better layout attained by application of this principle.

6. Index of Storage Space $= \frac{q-u}{q}$

Initial Layout	Revised Layout
$q = 648$	$q = 1890$
$u = 190$	$u = 135$
$\frac{q-u}{q} = .71$	$\frac{q-u}{q} = .93$

The improvement in this index is due to the elimination of the Final Storage Space. This space was provided in the original layout in order to handle the total oven load at the completion of each drying cycle. The continuous drying, while on the conveyor, in the new layout eliminated the need for this separate area.

This index does show that a decrease in storage space has been attained in the new layout.

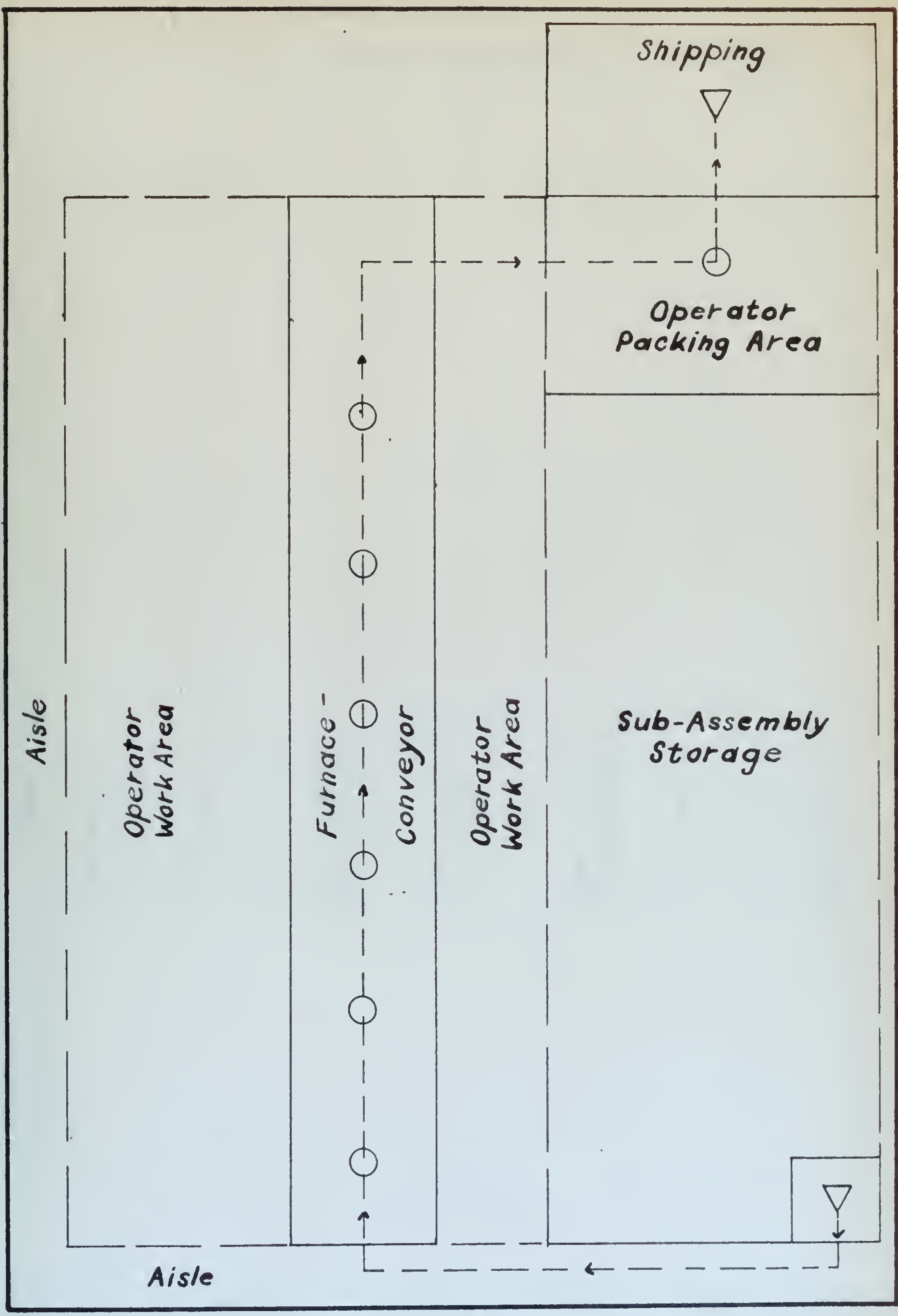


Fig. 5a-Initial Layout, Consolidated Ind.

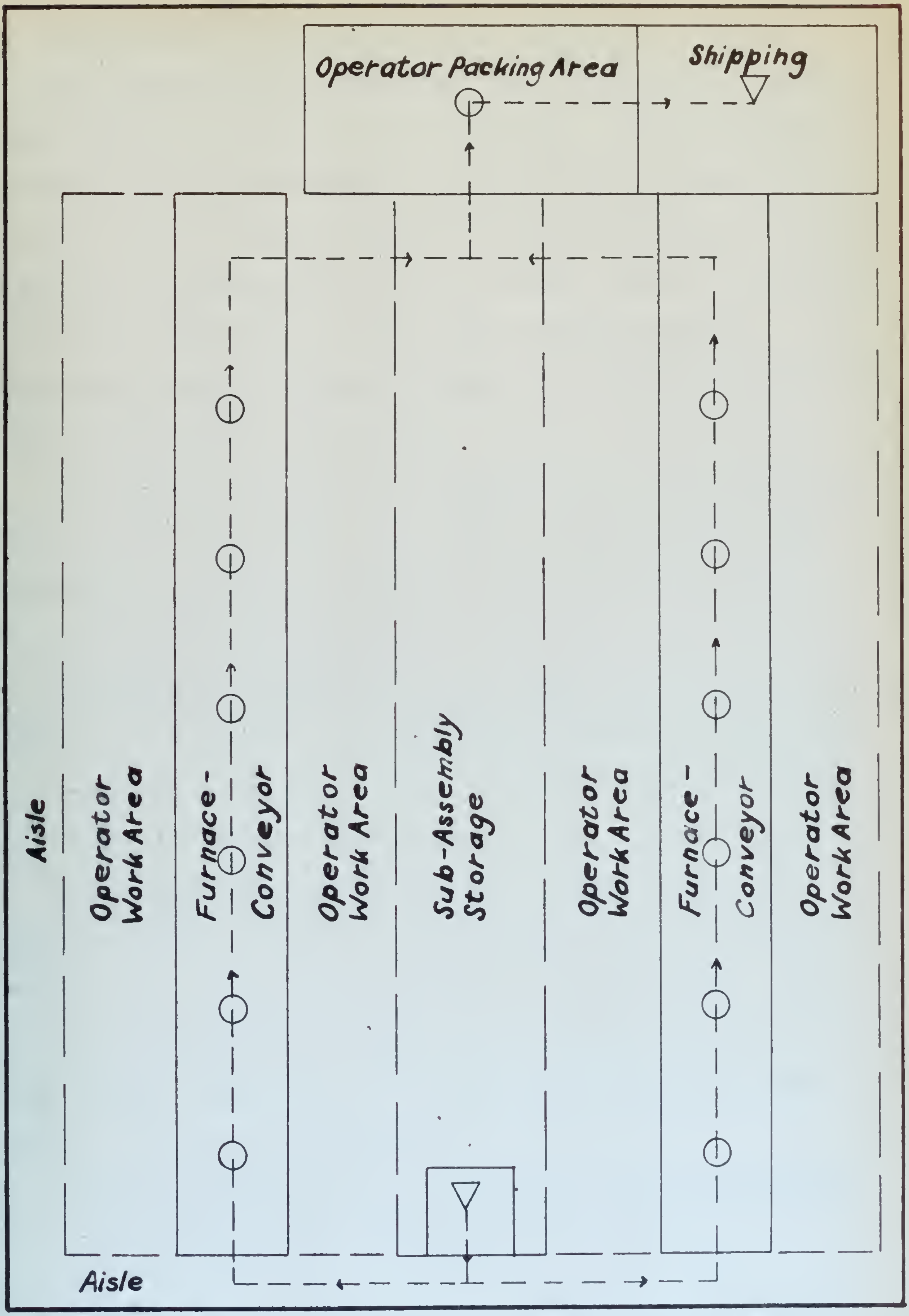


Fig. 5b - Revised Layout, Consolidated Ind.

IV Consolidated Industries, Inc., Lafayette, Indiana

The Consolidated Industries, Inc., manufactures heating equipment of varied types and sizes. One department is devoted to the production of a home-type Horizontal Gas Furnace. This furnace has proved popular, and the resultant demand for increased production created a need for expanded production facilities. Due to many external factors a re-layout was limited to the existing area presently devoted to the production of this furnace.

The previous production capacity was 50 Horizontal Gas Furnaces per day. With a new layout, employing the same processes, a production capacity of 100 Horizontal Gas Furnaces per day was realized.

Inasmuch as methods and floor area remained nearly constant in both layouts, the evaluation developed herein can be considered as being a fairly accurate appraisal of the actual physical-plant utilization.

This evaluation is developed from actual physical measurements of the plant, the re-layout being developed and installed during the preparation of this paper. The evaluation is based partially on the actual flow of the furnace assembly and partially on the use of operators and machines within the department.

<u>Layout Evaluation of the Horizontal Gas Furnace Dept.</u>

1. Index of Indirect Materials Handling $= \frac{a}{b}$

Initial Layout	Revised Layout
a = 47 ft.	a = 47 ft.
b = 73 ft.	b = 60 ft.
$\frac{a}{b}$ = .64	$\frac{a}{b}$ = .78

This index does show that the new layout utilizes a more efficient handling of the material. Although the actual conveyorized handling remains unchanged, the decrease in external handling causes the index to increase considerably in the new layout.

2. Index of Total Materials Handling = b

Initial Layout	Revised Layout
b = 73	b = 60

The same remarks apply as in (1) above. In the new layout the material handling route is laid out in a manner which provides a uniform flow equally well to either production line. This is due to centralizing of the Sub-Assembly Storage area between the two lines. The value of b remains the same when measured over either production line.

3. Index of Work Station Flexibility = $\frac{j_2}{k_2}$

Initial Layout	Revised Layout
j_2 = 10	j_2 = 20
k_2 = 11	k_2 = 22
$\frac{j_2}{k_2}$ = .91	$\frac{j_2}{k_2}$ = .91

The only machine, defined as such, not being capable of ready transfer to other locations, is the conveyor. The requirement of the new layout for twice the number of work

stations as well as two conveyors accounts for the unchanged value of this index.

4. Index of Floor Area Loading Density $= \dfrac{\sum[(m+2)(n+2)+p]}{q-(r+u)}$

Initial Layout	Revised Layout
$\Sigma = 771$	$\Sigma = 1126$
$q = 1100$	$q = 1172$
$r = 216$	$r = 216$
$u = 369$	$u = 188$
$\dfrac{\Sigma}{q-(r+u)} = 1.50$	$\dfrac{\Sigma}{q-(r+u)} = 2.78$

This index does measure a considerable increase in the efficient utilization of the plant floor area for productive capacity. The fact that both indices exceed the value of unity indicates that all spaces in the areas under consideration were designated as aisle space, storage space, operator work space or conveyor (machine) space. The addition of two feet around the conveyor as specified by the formula, creates the large values of the indices. There appears to be no objection to the value exceeding unity, other than the difficulty in making objective comparisons between industries or between factories within the same industry. There may be some actual waste area within the space designated for the operators. However, this space is marked off and no other activity may use it. The operator's work spaces are overlapping since all operators work in a standing position and move a short distance with each furnace as it progresses from one work station to the next.

5. Index of Aisle Space = $\frac{r}{q}$

Initial Layout	Revised Layout
$q = 1100$	$q = 1172$
$r = 216$	$r = 216$
$\frac{r}{q} = .20$	$\frac{r}{q} = .18$

The slight decrease in the value of this index is due to the retention of the same aisle area with a slight increase in the total plant floor area. The floor area was increased to allow for the Operator Packing area. The outlet from the Packing area in each layout is directly into the Shipping Room. The only aisle space required for this extra area is that necessary to accommodate the personnel (in this case, the personnel use the operator work area for access to their work station). Thus, a greater productive area in the new layout is serviced by the same aisle area. This does indicate a more efficient layout and such is reflected in this index.

6. Index of Storage Space = $\frac{q-u}{q}$

Initial Layout	Revised Layout
$q = 1100$	$q = 1172$
$u = 369$	$u = 188$
$\frac{q-u}{q} = .66$	$\frac{q-u}{q} = .84$

In-Process Storage is decreased in the new plant layout. The Storage space is more accessible to the production lines than it was in the old layout. The new arrangement of storage space still leaves much to be desired since the

operators near the storage area must pass certain component parts across the conveyor to the workers on the opposite side. More careful storage of sub-assemblies and component parts in the new Sub-Assembly Storage area made the decrease in space possible, while actually increasing the efficiency of distribution. This index does give an indication of the increase in plant floor area for productive purposes, due to the reduction in the space allotted to the storage of sub-assemblies.

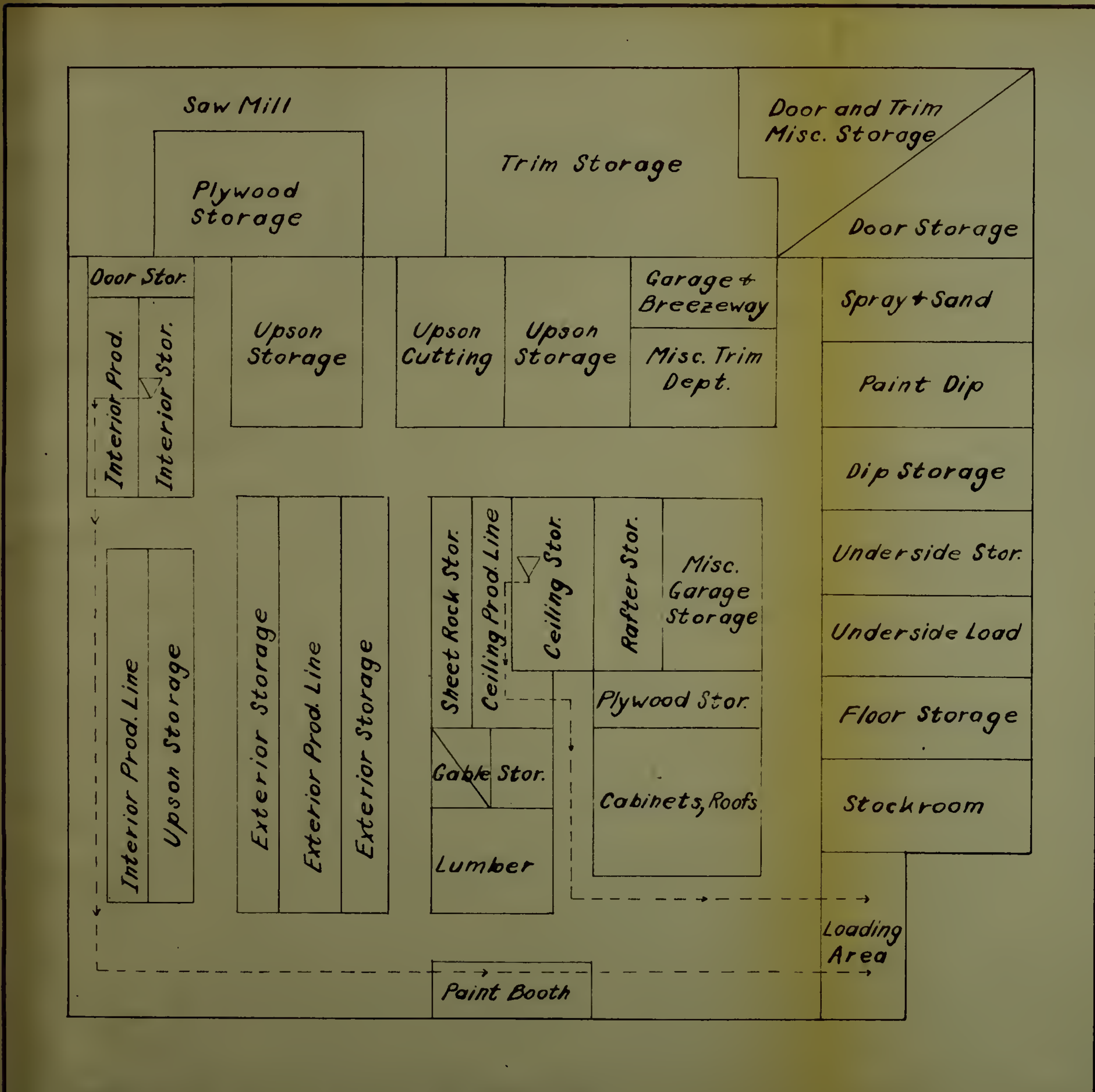


Fig. 6a - Initial Layout, National Homes, Incorporated

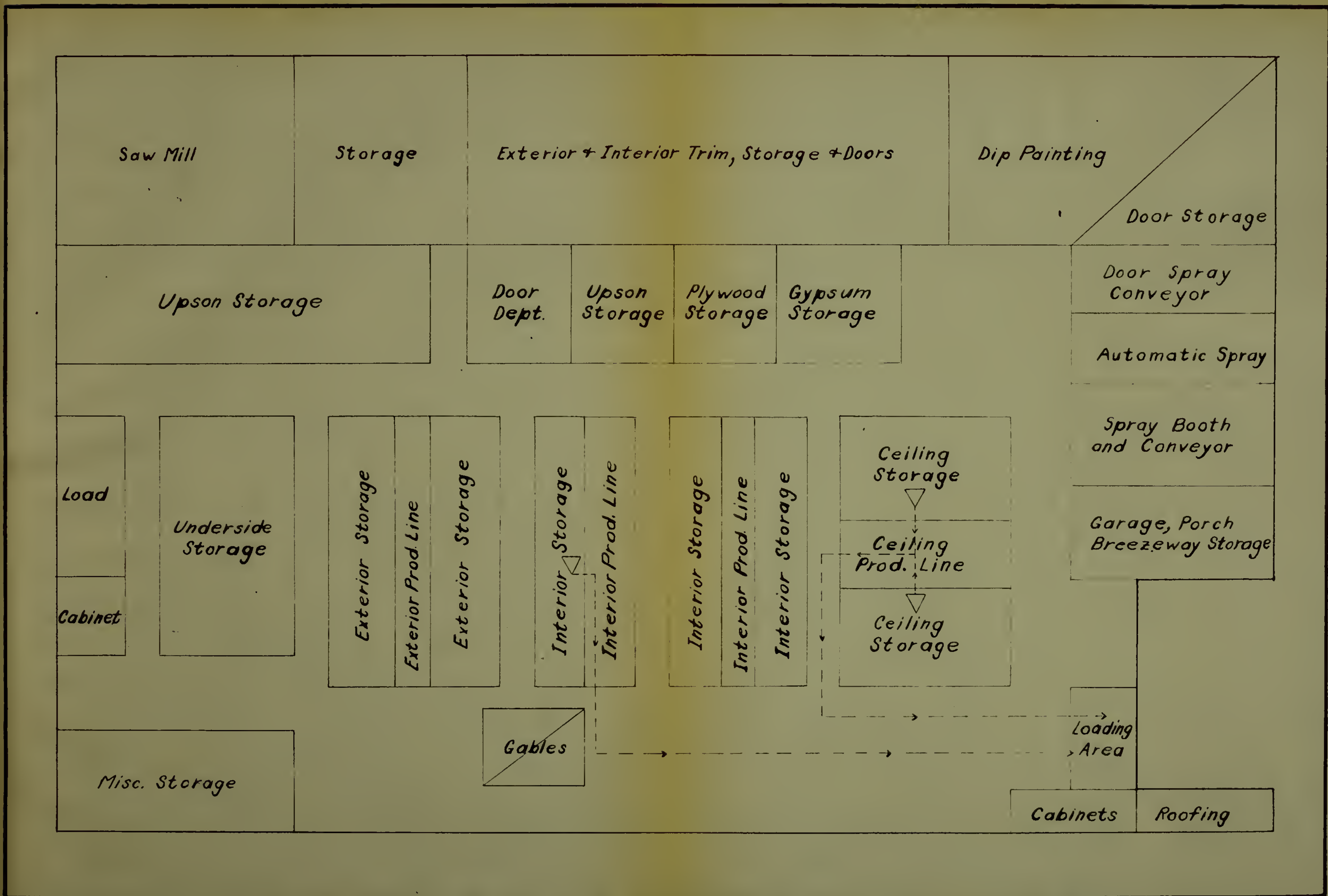


Fig. 6b - Revised Layout, National Homes, Incorporated

V National Homes Corporation, Lafayette, Indiana

The National Homes Corporation designs and builds prefabricated houses. This industry is relatively young and lacks the industrial experience available to many other types of manufacturers. Many of the processes in actual use have been developed through trial and error, while others are well established methods adapted to new uses. In view of this, many new and novel features are found in the layout of this plant.

The production area of the present plant occupies 109,680 square feet. This plant produces from 16 to 20 homes per shift per day. The proposed plant will occupy an additional 70,606 square feet. This plant will produce from 30-35 homes per shift per day. It is to be noted that the new layout entails no new processes. The increased production in the new plant is dependent on the increased capacity and more efficient layout of the production lines.

Reference to the layout plans will show that an unusual amount of plant space is occupied by in-process stores and spacious aisles. The very nature of the bulky raw materials makes this situation a necessity. Actually, the storage spaces occupy a much greater area than do the operator and machine spaces. This situation would be extremely dangerous, if not fatal, in most other industries.

In view of the peculiar production problems encountered, this plant provides an interesting and diversified layout

which, in turn, gives a good measure of the flexibility and application of the indices to be evaluated. Again, these indices will be evaluated from the standpoint of the flow of certain typical parts as well as from the standpoint of proper utilization of men and machinery.

Plant Layout Evaluation of National Homes Corp.

1. Index of Indirect Materials Handling $= \frac{a}{b}$

This index was measured in relation to the flow of two major items in both layouts. One item flow involved the assembly and handling of an Interior Wall. The other item flow involved the assembly and handling of a Ceiling Panel.

Interior Wall Line

Initial Layout	Revised Layout
a = 39'	a = 33'
b = 453'	b = 326'
$\frac{a}{b}$ = .086	$\frac{a}{b}$ = .101

The large ratio between the distance the part moves on the actual production line to the distance it moves from stores to shipping is a result of the type of production encountered. Actually, almost the entire route over which the Interior Wall flows consists of a monorail type conveyor. The panels are pushed by one man. Large moves are encountered for all fabricated parts due to the tremendous amount of space required for all component parts of the completed assembly. The new layout does provide for a considerably shorter route, and a resultant decreased ratio in the indirect materials

handling of the Interior Wall. This result is shown by this index.

Ceiling Panel Line

Initial Layout	Revised Layout
a = 26'	a = 39'
b = 196'	b = 244'
$\frac{a}{b} = .132$	$\frac{a}{b} = .160$

The same remarks apply here as applied to the Interior Wall Line. Although the overall actual distance the Ceilings moved was increased in the new layout, the conveyorized portion of movement was increased to a greater extent, resulting in a higher Index of Indirect Materials Handling.

2. Index of Direct Materials Handling = b

Interior Wall Line

Initial Layout	Revised Layout
b = 453'	b = 326'

This particular item enjoyed a considerable savings in direct materials handling in the new layout. The exact increase in efficiency in this phase is readily shown by this index.

Ceiling Panel Line

Initial Layout	Revised Layout
b = 196'	b = 244'

Here, the direct material handling was increased by 48'. In this particular line the increase was due to a re-location of in-process storages in order to facilitate distribution to two Ceiling Panel Lines in the new layout. The old layout

required only one line and hence provided for a shorter flow of material.

3. Index of Floor Area Loading $= \frac{\sum[(m+2)(n+2)+p]}{q-(r+u)}$

Initial Layout	Revised Layout
Σ = 26,238 sq.ft.	Σ = 35,377 sq.ft.
q = 109,680 sq.ft.	q = 156,666 sq.ft.
r = 23,482 sq.ft.	r = 33,637 sq.ft.
u = 45,961 sq.ft.	u = 63,963 sq.ft.
$\frac{\Sigma}{q-(r+u)} = .653$	$\frac{\Sigma}{q-(r+u)} = .579$

This index discloses that the use of productive plant floor area in the new layout has been decreased. Much of the raw material previously stored out of doors has been placed inside the new building. This material, although not included in the above figures does cause some trouble in estimation of aisle areas and working spaces to be assigned to such materials. Access area to in-process stores has been increased. In the old layout, operators did not have sufficient freedom of movement between in-process storage areas and operating areas. This access area is not included in the above dimensions and may account for part of the decreased value in the index.

4. Index of Aisle Space $= \frac{r}{q}$

Initial Layout	Revised Layout
q = 109,680 sq.ft.	q = 156,666 sq.ft.
r = 23,482 sq.ft.	r = 33,637 sq.ft.
$\frac{r}{q} = .214$	$\frac{r}{q} = .214$

There is no indicated change in the index of Aisle Space. It would seem coincidental that the same ratio should hold for both layouts. At any rate, such a ratio may be the optimum desired in this type of production or it may be the result of stereotyped planning of layouts.

5. Index of Storage Space = $\frac{q-u}{q}$

Initial Layout	Revised Layout
q = 109,680 sq.ft.	q = 156,666 sq.ft.
u = 45,961 sq.ft.	u = 63,963 sq.ft.
$\frac{q-u}{q}$ = .58	$\frac{q-u}{q}$ = .59

The new plant has a slightly decreased amount of in-process storage space in relation to the operating area available. This is a desirable situation, especially so when the stored material is of such a bulky nature and so difficult to handle. Reduced in-process storage in a plant of this nature has real dollar value in lowered production costs. The more efficient use of in-process storage space is pointed out by this index.

Index Name	Layout	Duncan Electric	Machine Dept., NOPI	Inspection Div., NOPI	Peerless Wire Co.	Consolidated Industries	National Homes, Inc.
Index of Indirect Materials Handling	Initial	.183			.46	.64	.086 .132
	Revised	.456			.83	.78	.101 .160
Index of Total Materials Handling	Initial	.527			65	73	453 196
	Revised	.76			126	60	326 244
Index of Gravity Utilization	Initial	.234					
	Revised	—					
Prime Index of Automatic Machinery Loading	Initial		.75				
	Revised		.88				
Secondary Index of Automatic Machinery Loading	Initial						
	Revised						
Index of Production Line Flexibility	Initial	.588					
	Revised	.625					
Index of Work Station Flexibility	Initial		.84	1.00		.91	
	Revised		.85	1.00		.91	
Index of Floor Area Loading Density	Initial	.403	.743	.56	.95	1.50	.653
	Revised	.198	.736	.84	.90	2.78	.579
Index of Aisle Space	Initial	.53	.42	.18	.22	.20	.214
	Revised	.24	.32	.19	.11	.18	.214
Index of Storage Space	Initial			.91	.71	.66	.58
	Revised			.89	.93	.84	.59
Index of Storage Volume Utilization	Initial	.45 .35					
	Revised	.85 .85					

Table 1 - Summary of Index Values

CRITIQUE

This critique will be concerned with the applicability, function and significance of each of the criteria, as retained, modified or proposed in this paper.

1. Index of Indirect Materials Handling $= \frac{a}{b}$

where a = the sum of the distances a part moves automatically by conveyor and from machine to machine arranged in operation sequence without external materials handling.

and b = the total actual distance a part moves via the production route from the entrance to the layout area to the exit from the layout area.

This index is consistent and accurate. It is a good measure of the efficiency of the production route with respect to mechanized handling of materials. This index was successfully used in all situations. It is recommended as an index of physical-plant utilization.

2. Index of Total Materials Handling = b

where b = the total actual distance a part moves via the production route from the entrance to the layout area to the exit from the layout area.

This index has proven to be a means of more easily comparing plants or areas manufacturing the same type of product. It

readily portrays the manner in which the production routes are laid out. Results were valid in each case in which this index was used. It is recommended that this index by used as a measure of physical-plant utilization.

3. Index of Gravity Utilization $= \frac{d}{e}$

where d = the sum of the vertical distances gravity feed is used in a multi-story plant.

and e = the total vertical distance up or down a part moves, involving machine or human effort, from the entrance to the layout area to the exit from the layout area, of a multi-story building.

Although sufficient opportunities were not available to fully evaluate the index, as defined above, it is felt that the limitations perceived in the former index have been overcome. The restricted application to multi-story buildings should alleviate the shortcomings in comparing layouts between single-story and multi-story buildings. This index should be retained as a measure of physical-plant utilization.

4. Prime Index of Automatic Machinery Loading $= \frac{f}{100g}$

where f = the sum of the percentages of machine down time from all cases where the individual percentages of down time are equal to or less than 50% of the individual work cycles.

and g = the total number of operators on those machines.

This index has been evaluated successfully and is considered to give an accurate indication of multi-machine layout. It was used without change or modification. It is recommended that this index be retained as a measure of physical-plant utilization.

5. Secondary Index of Automatic Machinery Loadings $= \frac{h}{100g}$

where h = the sum of the percentages of machine down time from all cases where the individual percentages of down time are greater than 50% of individual work cycles.

and g = the total number of operators on those machines.

This index was not evaluated since no situation occurred, during the preparation of this paper, in which this index could be properly used. From the experience gained in using Index #4, it appears that this index would also be applicable, without change or modification, as an index of physical-plant utilization.

6(a). Index of Production Line Flexibility $= \frac{j_1}{k_1}$

where j_1 = the number of machines or work stations performing operations on the part under consideration, so designed as to be capable of being moved to a new location in the same production line in one working shift.

and k_1 = the total number of machines or work stations performing operations on the part under consideration, in the production line.

This index was developed from the originally proposed Index of Flexibility. When used as a measure of machine flexibility in the production line, in relation to the flow of the part, it is considered a satisfactory index for physical-plant evaluation.

6(b). Index of Work Station Flexibility = $\frac{j_2}{k_2}$

where j_2 = the number of machines or work stations, within the area under consideration, so designed as to be capable of being moved to any other location in one working shift.

and k_2 = the total number of machines or work stations within the area under consideration.

This index, too, was developed from the Index of Flexibility. In terms of utilization of men and machinery, it proved to be a successful measure of machine and work station arrangements. It is recommended as an index of physical-plant utilization.

7. Index of Floor Area Loading Density = $\frac{\sum[(m+2)(n+2)+p]}{q-(r+u)}$

where m = extreme machine length in feet.

n = extreme machine width in feet.

p = the total work area normally required by an operator in the performance of his job.

q = total layout floor area in square feet.

r = total aisle area in square feet.

and u = total floor area, in square feet, occupied by temporary or controlled storage of material, or tools and equipment required to modify this material.

After revision, this index proved to be very sensitive to changes in the use of floor areas. Although it is not limited in value to unity as a maximum, it is, nevertheless, a valuable measure of the efficient utilization of floor space for productive purposes. This index proved valid in every case in which it was tested. It is recommended as an index of physical-plant utilization.

8. Index of Aisle Space = $\frac{r}{q}$

where q = total layout floor area.

and r = total aisle area.

Increases or decreases in aisle area were readily reflected in this index. It was used to measure the over-all utilization of layout floor areas for aisles. The measurements were accurate and responsive in every case. As re-defined here, this index is considered to be a good measure of physical-plant utilization.

9. Index of Storage Space = $\frac{q-u}{q}$

where q = total layout floor area

and u = total floor area occupied by temporary or controlled storage of material, or tools and equipment required to modify this material.

This index was also used successfully in each case tested. It is a newly proposed index and is considered to be a precise indicator of the utilization of layout floor area for storage of in-process materials and related items. This index should be retained as a measure of physical-plant utilization.

10. Index of Storage Volume Utilization = $\frac{v}{w}$

where v = volume occupied by raw materials or finished goods at the normal maximum attainable level of storage.

and w = total volume available for storage of raw materials or finished goods.

This index was proposed too late, in the development of this paper, for proper evaluation in all of the existing plants. In the one test conducted, it showed promise of being a good measure of the cubage utilization of storage spaces, as well as a measure of the means of obtaining this utilization. This index requires further evaluation, but in view of its satisfactory employment thus far it, too, is recommended as an index of physical-plant utilization.

CONCLUSIONS AND RECOMMENDATIONS

Ten indices of effective physical-plant utilization were originally proposed. In the validation of these indices, by actual application to industrial situations, certain changes appeared desirable. These changes included generalizing and clarifying the terms used, and re-defining certain other terms for more universal ease in application. Two indices were set aside as being measures of methods or processes, rather than measures of layout. During the evaluation, two additional indices of plant layout were proposed and partially validated.

Those indices which were retained appear well suited for the evaluation of either continuous or intermittent manufacturing layouts. However, in applying the indices to actual plant layouts, a more natural grouping order was evolved. This order seemed to be superior to grouping by type of manufacture. In this arrangement the indices would be grouped as follows:

<u>Flow of the Manufactured Part</u>

1. Index of Indirect Materials Handling

2. Index of Total Materials Handling

3. Index of Gravity Utilization

6(a). Index of Production Line Flexibility

<u>Utilization of Men and Machinery</u>

4. Prime Index of Automatic Machinery Loading

5. Secondary Index of Automatic Machinery Loading

6(b). Index of Work Station Flexibility

7. Index of Floor Area Loading Density

8. Index of Aisle Space

9. Index of Storage Space

10. Index of Storage Volume Utilization

The above indices may be used separately or in combinations, depending on the particular situation encountered. There is an advantage noted in analyzing the numerical values of certain indices with respect to one another. Significant results may be obtained by further work in the inter-correlation of the values of all the indices. In doing this, it is recommended that the investigation of the indices be developed through mathematical representations such as alignment charts, or Nomograms. Such a treatment would provide for easier application of the indices, and might also derive the optimum values obtainable under certain conditions of layout.

The indices evaluated and retained in this paper are now considered to be valid criteria of physical-plant utilization. Further research not far afield might include the development of general standards of index values within industries, the correlation of index values with common industrial criteria, and the development of a similar set of indices for other Industrial Engineering techniques.

APPENDIX A

Calculation Information

Further research in the field covered by this paper might be aided by a knowledge of the time required for the gathering of the necessary information to calculate the indices contained herein.

The approximate time required in each of the plants, for purposes of gathering this information, is as follows:

Plant	Time Required
Duncan Electric Co.	40 hours
Naval Ordnance Plant	32 hours
Peerless Wire Products	10 hours
Consolidated Industries	10 hours
National Homes	24 hours

It is to be noted that the time spent in obtaining the necessary data is dependent on many factors such as complexity of manufacturing processes, layout of plant, and accuracy of plant records and files. The above data does not include the time required for analyzing, simplifying, and evaluating the information for use in the plant layout indices.

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